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To perseverance,
To family, friends, colleagues, and collaborators,
Without whom no PhD thesis would ever be completed

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During the past few months leading up to the defence, I have come to the realization that some choices in life – even if originally propelled by arbitrary coincidences – ultimately embody this quote from a poem by Tommy

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"*It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair…*" (A Tale of Two Cities, Charles Dickens, 1859).

It was all this and more, a microcosmos of life, embodied in a decade of living with a doctoral project. I learnt much, felt more, and am forever grateful for the experience.

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Carina Saarela

List of original publications

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II. *Saarela*, *C.*, Karrasch, M., & Laine, M. Age-invariant valence-arousal interactions in free recall and recognition memory. Manuscript submitted for publication.

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IV. *Saarela, C.*, Karrasch, M., Ilvesmäki, T., Parkkola, R., Rinne, J. O., & Laine, M. (2016). The relationship between recognition memory for emotion-laden words and white matter microstructure in normal older individuals. *NeuroReport, 27*, 1345-1349. doi: https://dx.doi.org/10.1097/WNR.0000000000000704

Svensk sammanfattning

Hälsosamt åldrande kan karaktäriseras som en mångdimensionell process, som omfattar såväl åldersrelaterad fysisk/kognitiv funktionsnedsättning som bibehållen funktionsnivå inom socioaffektiva och specifika kognitiva domäner. Detta gäller även för episodiskt minne, eftersom hälsosamt åldrande samtidigt omfattar allmän minnesnedsättning och bibehållen emotionell förstärkningseffekt på minne (*emotional enhancement effect in memory*, EEM). EEM innebär att det emotionella innehållet i informationen underlättar skapandet av minnesspår för informationen och förstärker dessa minnesspår. Inom detta forskningsområde begreppsliggörs emotion vanligtvis som två tvåriktade dimensioner, valens (negativ-positiv) och arousal (lugnande-eggande). Även om EEM bibehålls med stigande ålder, förekommer åldersskillnader hos de valensspecifika preferenserna för information med emotionellt innehåll. Denna så kallade positivitetseffekt kan observeras i form av en minskad preferens för negativt framom positivt material, som är typisk för unga vuxna, eller i form av en preferens för positivt framom negativt material (positivitetsbias) hos medelålders och äldre personer. Hjärnavbildningsfynd påvisar även åldersskillnader i aktiveringsmönster och funktionella kopplingsmönster i EEM-relaterade hjärnområden. Eftersom studierna inom detta forskningsområde är relativt få, är de psykologiska och neurala mekanismerna bakom dessa åldersskillnader emellertid rätt okända.

Den övergripande målsättningen för föreliggande avhandling var att undersöka de psykologiska och neurala mekanismerna för minne för ord med emotionellt innehåll vid åldrande. Först skapades ålders- och könsspecifika normer för evalueringar av valens och arousal för 420 frekvenskontrollerade finska substantiv (Studie I). Dessa normer användes för att välja stimuli för de tre följande studierna (Studierna II-IV). Dessa studier syftade till a) att utreda arousal-dimensionens roll för åldersskillnader hos valensspecifika preferenser i episodiskt minne; och b) att undersöka de hjärnanatomiska korrelaten för minne för ord med emotionellt innehåll hos kognitivt sett friska medelålders och äldre personer. Minnet för avsiktligt inlärda ord undersöktes med hjälp av uppgifter som mätte omedelbar återkallning i minnet och igenkänningsminne. De hjärnanatomiska korrelaten av intresse utgjordes av lokal grå hjärnsubstansvolym och vit substansmikrostruktur mätt med hjälp av fraktionerad anisotropi (FA) genom strukturella magnetiska resonansavbildningsmetoder (MRI).

Studie I bekräftade i stort det förväntade kurvilinjära sambandet mellan valens- och arousal-evalueringar, men negativa och positiva ord uppvisade distinkta samband. Effekterna av ålder och kön på evalueringarna var svaga men statistiskt signifikanta, och huvudsakligen i enlighet med förväntningarna. Evalueringarna korrelerade till övervägande del med evalueringar i andra databaser. Eftersom valensfaktorn förklarade betydligt större proportion av variansen i evalueringarna, tyder fynden på större betydelse av språkliga och kulturella faktorer än demografiska karaktäristika för evalueringar av affektiva egenskaper hos ord.

Studie II undersökte arousal-dimensionens roll för åldersrelaterade valensspecifika preferenser i episodiskt minne i en grupp unga vuxna och en grupp medelålders och äldre personer. I motsats till förväntningarna uppstod inga statistiskt signifikanta åldersskillnader gällande effekterna av valens och/eller arousal på omedelbar återkallning i minnet eller igenkänningsminnesprecision eller -svarsbias. Således framkom ingen åldersrelaterad positivitetseffekt, utan enbart generellt nedsatt minnesprecision hos de äldre personerna. Valens och arousal uppvisade distinkta, men mestadels interagerande effekter för dessa mått.

Studierna III och IV utredde de lokala grå substansvolymetriska korrelaten och de mikrostrukturella korrelaten i den vita hjärnsubstansen för minne hos medelålders och äldre personer. De beteendemässiga resultaten uppvisade en oväntad positivitetsbias och EEM i igenkänningsminne (Studierna III-IV), men ingen effekt av emotion på omedelbar återkallning i minnet (Studie III). I **Studie III** uppvisade de regionspecifika analyserna för amygdala- och hippokampusvolymer inga associationer med minnesprestationer. Helhjärneanalyserna uppvisade oväntat att bättre omedelbar återkallning i minnet av negativa ord hade ett samband med mindre lokal grå substansvolym i dorsomediala och vänstra dorsolaterala prefrontala cortex. Den signifikanta positiva korrelationen mellan lokal grå substansvolym och omedelbar återkallning i minnet av positiva ord lokaliserades överraskande till lillhjärnan och den negativa korrelationen för igenkänningsminne för positiva ord till primära visuella cortex. Dessa fynd tyder på att de hjärnområden som stödjer minne för information med emotionellt innehåll omfattar bakre hjärnområden, inklusive lillhjärnan, och att kognitiva kontrollfunktioner kan utgöra den drivande mekanismen för emotionellt minne. I **Studie IV** framkom inga statistiskt signifikanta samband mellan FA och igenkänningsminne för negativa eller neutrala ord. Däremot noterades negativa korrelationer mellan igenkänningsminne för positiva ord och FA i flera projektions- och associationsbanor samt kommissurer i vänstra hjärnhalvan. Detta reflekterar sannolikt att sambanden mellan positivitetsbias i episodiskt minne, strukturell integritet hos den vita substansen och kompensatoriska hjärnmekanismer är komplexa hos äldre personer.

Studierna II-IV påvisade betydelsen av att beakta effekterna av såväl valens som arousal på emotionellt minne. I Studierna I-II varierade det inbördes förhållandet mellan dessa affektiva dimensioner under olika betingelser, vilket indikerar att sambandet mellan dem är mångsidigt till sin natur. Flera nya fynd framkom i de hjärnanatomiska Studierna III-IV. De oväntade lokaliseringarna och riktningarna för korrelationerna i dessa studier påvisar att struktur-funktion-sambanden för emotionellt minne uppvisar unika kvaliteter vid hälsosamt åldrande. Detta tyder på att dessa hjärnanatomiska korrelat kan vara distinkta för hälsosamt åldrande och hjärnpatologiska tillstånd. Generellt sett, den kontraintuitiva riktningen hos vissa resultat betonade komplexiteten hos sambanden mellan hjärnstrukturers storlek/integritet, funktionella effektivitet och beteendemässiga utfall. Dessa empiridrivna studiers resultat var mer i enlighet med den kognitiva kontroll-/socioemotionella selektivitetsteoretiska modellen för positivitetseffekten än de bristbaserade dynamiska integrationsteoretiska- eller åldrande hjärnmodellen-modellerna. Ingen grupp bestående av unga vuxna inkluderades dock här. Därtill påvisade studie II, som inkluderade unga vuxna, knappt stöd för någondera teoretiska modelltypen och inga bevis för den åldersrelaterade positivitetseffekten i minne. För att precisera de drivande mekanismerna för dessa resultat behövs integrativa studier, som skulle samla flernivå- och mångdimensionellt data för att analysera och skapa modeller som tillåter bedömning av distinkta bidrag av olika processer såväl som av deras inbördes förhållanden. Kunskapen om emotionellt minne vid åldrande skulle även befrämjas av användning av mer ekologiskt valida stimuli, såsom virtuella verklighetssystem.

Abstract

Healthy aging can be characterized as a multidimensional process that involves both age-related physical/cognitive deterioration and preserved functioning in socioaffective domains and specific cognitive abilities. This is also true for episodic memory, as healthy aging simultaneously entails general episodic memory decline and preserved emotional enhancement effect in memory (EEM). EEM is defined as the augmentation of the formation and strength of memory traces for emotion-laden information. In this field of research, emotion is commonly conceptualized as two bidirectional dimensions, valence (negative-positive) and arousal (calming-exciting). Even though EEM is maintained with age, age differences tend to emerge in the valence-specific preferences for emotion-laden information. This so-called positivity effect can manifest as a reduced preference for negative over positive material commonly seen in young adults, or even as a preference for positive over negative material (positivity bias) in middle–aged and older adults. Neuroimaging evidence indicates that also the activation and functional connectivity patterns of EEM-related brain regions differ between young and older adults. However, due to the dearth of research in this particular field, the psychological and neural mechanisms of these age differences remain poorly known.

The overarching aim of the present thesis was to examine the psychological and neural mechanisms underlying memory for emotion-laden words in aging. First, age- and gender-specific norms for valence and arousal ratings for 420 frequency-controlled Finnish nouns were established (Study I). These norms were used to select stimuli for the three subsequent studies (Studies II-IV), which aimed at a) investigating the role of arousal in age differences concerning valence-specific preferences in memory; and b) examining the neuroanatomical substrates of memory for emotion-laden words in cognitively intact middle-aged and older adults. Memory was assessed using tasks probing immediate free recall and recognition memory of intentionally encoded words. The neuroanatomical correlates of interest were regional gray matter (GM) volume and white matter (WM) microstructure as measured by fractional anisotropy (FA) using structural magnetic resonance imaging (MRI) methods.

Study I mainly confirmed the expected curvilinear relationship between valence and arousal ratings, but with distinct relationships for negative and positive words. Effects of age and gender on the ratings were weak, but statistically significant, and mostly in line with expectations. The ratings correlated for the most part adequately with ratings in other databases. Because the valence factor explained decidedly more of the variance in the ratings, the findings indicate that language- and culture-related aspects take precedence over demographic characteristics when affective properties of words are rated.

Study II examined the role of arousal in producing the age-related valence-specific preferences in memory in a group of young adults and a group of middle-aged and older adults. Contrary to predictions, no statistically significant age differences emerged concerning valence and/or arousal effects on immediate free recall and recognition memory accuracy or response bias. Thus, no age-related positivity effect was found, only lower overall memory accuracy in the older adults. Valence and arousal exhibited distinct, but mostly interacting effects on these measures across the age groups.

Studies III and IV investigated the regional GM volumetric and WM microstructural correlates of memory in middle-aged and older adults. The behavioral results showed an unexpected positivity bias and EEM in recognition memory (Studies III-IV), but no effect of emotion on immediate free recall (Study III). In **Study III**, the region-of-interest (ROI) analyses using amygdalar and hippocampal volumes yielded no associations with either immediate free recall or recognition memory. The whole brain analyses unexpectedly showed that better immediate free recall of negative words was associated with less regional GM volume in dorsomedial and left dorsolateral prefrontal cortex (PFC). Surprisingly, the significant positive correlation between local GM volume and immediate free recall of positive words was located to the cerebellum, and the negative correlation for recognition memory of positive words to primary visual cortex. The findings suggest that the neural areas subserving memory for emotion-laden information involve posterior brain areas, including the cerebellum, and that cognitive control functions may constitute the driving mechanism for memory for emotion-laden information. In **Study IV**, no statistically significant associations between FA and recognition memory of negative or neutral words were found. Negative associations between recognition memory of positive words and FA were unexpectedly found in several left-hemisphere projection, association, and commissural tracts. This likely reflects the complex interrelationships between the positivity bias in memory, structural WM integrity, and compensatory brain mechanisms in older age.

Study II together with the behavioral results in Studies III-IV revealed that it is important to consider the contributions of both arousal and valence to emotional memory. In Studies I-II, the interrelatedness between these affective dimensions took different forms in different conditions, indicating that their relationship is variable by nature. The neuroanatomical Studies III-IV produced several novel findings. The unexpected localizations and directions of the correlations in these studies indicate that the structure-function relationships for memory for emotion-laden stimuli hold unique qualities in healthy aging, suggesting that these neuroanatomical correlates may be distinct for healthy aging vs. neuropathological conditions in older age. On a general level, the counterintuitive directionality of some of the results highlighted the complexity of the relationships between size/integrity of brain structure, functional efficiency, and behavioral outcomes. The results of these data-driven studies were more in line with the Cognitive Control Model/Socioemotional Selectivity Theory (CCM/SST) account of the positivity effect than the deficit-based Dynamic Integration Theory (DIT) or Aging Brain Model (ABM) accounts. However, no young adult group was included here. Furthermore, the behavioral study II, which did include young adults, offered scant evidence to support either theoretical framework, and showed no evidence for the age-related positivity effect in memory. To pinpoint the mechanisms driving these results, further studies using integrative frameworks are warranted. These should collect multilevel and multidimensional data to analyze and create models that permit assessing distinct contributions of various processes as well as their interrelationships. Also, using more ecologically valid stimuli, such as virtual reality systems, would advance knowledge on emotional memory.

Abbreviations and definitions

AAL	Automated Anatomical Labeling toolbox
ABM	Aging Brain Model
ACC	Anterior cingulate cortex
AD	Axial diffusivity
Affective space	The bivariate distribution of valence and arousal ratings plotted in a two-dimensional space
ANEW	Affective Norms for English Words
ANOVA	Analysis of variance
Arousal	Bidirectional affective dimension, denoting whether a stimulus is perceived as very calming (low-arousing) or very exciting (high-arousing)
BA	Brodmann area
BDI-II	Beck Depression Inventory-II
BET	Brain Extraction Tool
CCM	Cognitive Control Model
CERAD	Consortium to Establish a Registry for Alzheimer's Disease
DENN-BAWL	Discrete Emotion Norms for Nouns - Berlin Affective Word List
DIT	Dynamic Integration Theory
DTI	Diffusion tensor imaging
EEG	Electroencephalogram
EEM	Emotional enhancement effect in memory
Episodic memory	Memory for personally experienced and temporally restricted events or episodes
FA	Fractional anisotropy
FADE	Fronto-amygdalar age-related change in emotion
FDT	FMRIB Diffusion Toolbox
FNIRT	FMRIB's Linear Image Registration Tool
FWE	Family-wise error
FWHM	Full-width-at-half-maximum
GM	Gray matter
GRAPPA	Parallel acquisition technique
IAPS	International Affective Picture System
ISI	Inter-stimulus interval

ITI	Inter-trial interval
MADS	Madrid Affective Database for Spanish
MD	Mean diffusivity
MNI	Montreal Neurological Institute
MRI	Magnetic resonance imaging
MTL	Medial temporal lobe
NA	Negative affect
Negativity bias	Relative preference for negative over positive information, typically encountered in young adults
OFC	Orbitofrontal cortex
PA	Positive affect
PANAS	Positive and Negative Affect Schedule
Paradox of aging	The combination of age-related deterioration of various physical and cognitive processes and preserved functioning in socioaffective and some cognitive domains
PFC	Prefrontal cortex
Positivity bias	Relative preference for positive over negative information, may emerge in older adults
Positivity effect	An age-related qualitative shift in the valence-specific preferences for emotion-laden information, encompassing a reduced negativity bias or a positivity bias in middle and older adulthood
RD	Radial diffusivity
REF	Reference
Response bias	The propensity to respond 'old' (liberal response bias) or 'new' (conservative response bias) to any stimulus in an old-new recognition memory task
ROI	Region-of-interest
RT	Reaction time
SAM	Self-Assessment Manikin
SAVI	Theory on Strength and Vulnerability Integration
SST	Socioemotional Selectivity Theory
TBSS	Tract-based spatial statistics
TFCE	Threshold-Free Cluster Enhancement

WM	White matter
Valence	Bidirectional affective dimension, denoting whether a stimulus is perceived as negative (very unpleasant, low valence), positive (very pleasant, high valence), or neutral (no hedonic value)
VBM	Voxel-based morphometry

1. Introduction

"With mirth and laughter let old wrinkles come." (Shakespeare, trans. 1954, 1.1.84)

Affection. Praise. Chocolate. Rationale. Number. Insult. Desecration. Plague. If you engage in a moment's introspection, it should become clear that the words (and the associations that they evoked, maybe to personal memories) eliciting an emotional reaction or affecting your mood will probably be better recalled later, and/or that the memories of these words hold a more salient quality than the memories for the more mundane words. Among other things, memories for emotion-laden events tend to be more vivid and appear more personally meaningful. For example, contrast the memory for the first time you fell in love with that for brushing your teeth in the morning. This phenomenon has been coined *the emotional enhancement effect in memory* (EEM), which entails the reinforcement of the formation and strength of memory traces for emotion-laden information (for reviews, see e.g., Dolan, 2002; Hamann, 2001; Kensinger & Schacter, 2016). EEM can be observed in various memory domains, but the present thesis focuses on effects of emotion on *episodic memory*, defined as memory for personally experienced and temporally restricted events or episodes (Tulving, 2002). EEM does not develop in isolation: a generic processing advantage for emotion-laden information is well-established, entailing also augmented attention to emotionally salient stimuli (for reviews, see Dolan, 2002; Hamann, 2001; Kensinger & Schacter, 2016; for a meta-analysis, see Murphy & Isaacowitz, 2008). This processing advantage, and notably EEM, is preserved in middle and older adulthood (Kensinger & Gutchess, 2017; Murphy & Isaacowitz, 2008), despite the well-documented decline in the general level of working memory and episodic memory during the course of healthy aging (Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012). However, this general age-related memory decline can also be observed for emotion-laden information: even though middle-aged and older adults do show EEM, they still tend to be outperformed by young adults also on memory measures for emotion-laden information (for a review, see Kensinger & Gutchess, 2017). The combination of age-related deterioration of various physical and cognitive processes and preserved functioning in socioaffective and some cognitive domains is nowadays considered as a key characteristic of healthy aging (Kensinger & Gutchess, 2017), coined as "the paradox of aging" (Charles & Hong, 2016). This paradox acknowledges that healthy aging is a multifaceted process (Charles & Hong, 2016; Kensinger & Gutchess, 2017) with heterogeneity in individual trajectories (Nyberg et al., 2012; Raz & Daugherty, 2018). Earlier, research into psychological aging processes largely focused on deterioration of physical and mental capacities and concurrent neural degeneration (Kensinger & Gutchess, 2017; Reed, Chan, & Mikels, 2014), thus inadvertently creating a bleak vision of aging as a time of loss, grief, and adapting to the proximity of death. Only in recent years, a more balanced view of later life simultaneously characterized as a time of increased emotional well-being (Charles & Carstensen, 2010; Charles & Hong, 2016) and a time of reaping the fruits of wisdom accumulated over a lifetime's worth of experience (Kensinger & Gutchess, 2017) has emerged. The preservation of EEM seems to be confined to healthy aging, as research on memory for emotion-laden information in pathological aging has yielded mixed findings (e.g., Gorenc-Mahmutaj et al., 2015; Mammarella & Fairfield, 2014; Nieuwenhuis-Mark, Schalk, & de Graaf, 2009).

A matter for debate, as well as the object of voluminous research efforts, is whether memory for emotion-laden information in healthy aging can also be characterized by an age-related qualitative shift in the valence-specific preferences for emotion-laden information (Mather & Carstensen, 2005; Reed & Carstensen, 2012; Reed et al., 2014), called *the positivity effect* (Kennedy, Mather, & Carstensen, 2004). The age-related positivity effect is described in terms of two bidirectional dimensions outlined in the circumplex theory of emotion (Russell, 1980), namely *valence* (Pleasure-Displeasure) and *arousal* (Deactivation-Activation) (Russell, 2003). The circumplex theory represents a dimensional account of the nature and structure of emotion, where emotions are seen to be constructed from basic building blocks, or dimensions of common descriptive features (e.g., Barrett & Wager, 2006). It stands in contrast to the categorical account that considers emotions to represent discrete and specific categories of prototypical emotional states, such as fear or joy (e.g., Barrett & Wager, 2006). In terms of stimulus characteristics, *valence* indicates whether the stimulus is perceived as negative (very unpleasant, low valence), positive (very pleasant, high valence), or neutral (no hedonic value). The opposite poles on the *arousal* dimension indicate whether the stimulus is perceived as very calming (low-arousing) or very exciting (high-arousing). From this perspective, a stimulus provoking a reaction of fear is usually considered high-arousing and negatively valenced, whereas a stimulus provoking joy is also evaluated as high-arousing, but positively valenced. A schematic representation of the relationship between the dimensional and categorical accounts of the nature and structure of emotion is depicted in Figure 1.

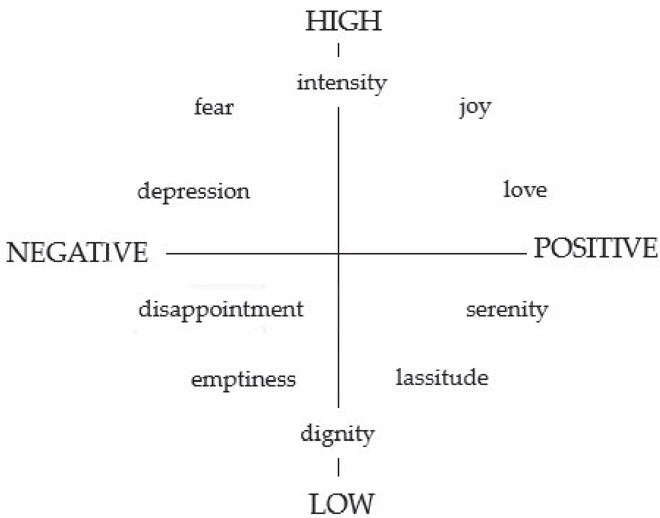

Figure 1. Emotion categories arranged on the valence (horizontal axis) and arousal (vertical axis) dimensions of the circumplex theory of emotion (Russell, 1980, 2003). Mean valence and arousal ratings for these words (in Finnish) were obtained from the database in Söderholm, Häyry, Laine, & Karrasch (2013; Study I).

Young adults tend to manifest a *negativity bias*, indicating a relative preference for negative over positive information (e.g., Grühn, Smith, & Baltes, 2005; Kensinger, 2008; Kensinger & Schacter, 2008; Reed et al., 2014). The age-related positivity effect entails a diminution of this negativity bias in middle-aged and older adults (e.g., Charles, Mather,

& Carstensen, 2003; Kensinger & Schacter, 2008), or even a replacement of it with a *positivity bias*, that is, a relative preference for positive over negative information (e.g., Kensinger, 2008; Mather & Knight, 2005; for a meta-analysis, see Reed et al., 2014). The role of arousal in generating the positivity effect has been somewhat neglected, with rather few behavioral studies addressing this issue (Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Kensinger, 2008; Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). This is quite remarkable given that for a long time, arousal rather than valence was conceived as the main driving force behind EEM (Bradley, Greenwald, Petry, & Lang, 1992; Kensinger & Corkin, 2003; Russell, 2003). Nowadays, the two dimensions are thought to contribute to the encoding, consolidation, and retrieval of memory traces via distinct, yet interacting cognitive and neurobiological processes (for a review, Dolcos et al., 2017). Some studies on the contribution of arousal to the age-related positivity effect have suggested that arousal exerts a modulatory influence on the valence-specific age-related differences in memory (Kensinger, 2008), but the evidence is mixed (cf. Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). Elucidating the manner in which valence and arousal conjointly help shape memory for emotion-laden information in normal aging would be pivotal to gain a better understanding of the mechanisms that drive the age-related positivity effect in memory.

As memory for emotion-laden events and stimuli has been shown to exhibit unique characteristics at the behavioral level, a large number of studies have addressed its neural underpinnings. So far, lesion studies (e.g., Adolphs, Cahill, Schul, & Babinsky, 1997; Phelps, LaBar, & Spencer, 1997) and functional neuroimaging studies using young adult participants (e.g., Canli, Zhao, Desmond, Glover, & Gabrieli, 1999; Dolan, Lane, Chua, & Fletcher, 2000; Hamann, Ely, Grafton, & Kilts, 1999; Kensinger & Corkin, 2004; Tabert et al., 2001) have delineated an extensive network of cortical and subcortical brain areas that are engaged in memory tasks with emotion-laden stimuli. The age-related positivity effect in memory hints at concomitant differences in the neural underpinnings for processing of emotion-laden information, but functional and structural neuroimaging studies on EEM and valence-specific memory performance in middle and older age remain scant.

The few existing functional neuroimaging studies point to age differences in strength of activation in brain areas found to subserve EEM, in activation loci (Fischer, Nyberg, & Bäckman, 2010; Kensinger & Schacter, 2008), and even in valence-specific neural correlates (Kensinger & Schacter, 2008). Age differences in functional brain connectivity patterns have also been demonstrated (Addis, Leclerc, Muscatell, & Kensinger, 2010; Ford, Morris, & Kensinger, 2014; St Jacques, Dolcos, & Cabeza, 2009), although the results have been inconsistent (Addis et al., 2010; Ford et al., 2014; St Jacques et al., 2009).

The principal aim of this thesis was to study neurocognition of memory for emotion-laden words in healthy aging. This was done by examining a) the effects of valence and arousal on immediate free recall and recognition memory in healthy young and older adults; and b) the neuroanatomical correlates of memory for emotion-laden words in healthy middle-aged and older adults. Most functional neuroimaging studies tend to focus on the most consistent activation loci across individuals, which results in the removal of variability in behavior and brain function by averaging. By contrast, as structural neuroimaging studies are conducted using a correlational approach, they reveal the associations embedded in the inter-individual variability of behavior and brain structure (Kanai & Rees, 2011). The general assumption of structure-function studies is that the size (volume) of given brain structures (e.g., Gautam, Cherbuin, Sachdev, Wen, & Anstey, 2011), or the structural integrity of the white matter (WM) tracts connecting given areas (e.g., Jones, Knösche, & Turner, 2013) are positively correlated with their functional efficiency. The different measures obtained by diffusion tensor imaging (DTI) are thought to reveal subtle variations in various microstructural properties of WM tracts, such as those occurring in normal aging (Bennett & Madden, 2014; Salat et al., 2009). In the present thesis, associations between memory for emotion-laden words and WM microstructure tapped by fractional anisotropy (FA) are reported. High FA levels are thought to indicate high axonal density, reduced axonal calibre, high degree of myelination, or low membrane permeability (Jones et al., 2013). Therefore, higher FA values supposedly index more effective neuronal conduction via WM tracts (Kanai & Rees, 2011) by influencing the speed and energy efficiency of action potentials (Scholz, Tomassini, & Johansen-Berg, 2014). In turn, decreased FA is assumed to indicate microstructural alterations in the

WM tracts, resulting in inefficient neuronal conduction, and ultimately slower neural transmission (Jones et al., 2013; Kanai & Rees, 2011). In other words, bigger (more volume) means better, and higher microstructural integrity means faster. Increasing age has been shown to entail increased variability in regional gray matter (GM) volume of memory-related areas (Grieve, Clark, Williams, Peduto, & Gordon, 2005; Jernigan et al., 2001; Van Petten, 2004), in the microstructural properties of WM tracts (Brickman et al., 2012; Lebel et al., 2012; Mårtensson et al., 2018; Salat et al., 2009), and in memory performance (Nyberg et al., 2012; Van Petten, 2004). Therefore, examining the regional GM volumetric and WM microstructural correlates of emotional memory performance in middle-aged and older adults could shed light on the mechanisms of age-specific features of this memory domain. Moreover, the functional implications of alterations in the integrity of a brain region in terms of its GM volume are ultimately related to its connections with other brain regions (for a review, se Mather, 2016), and hence, to the structural integrity of these connections. Consequently, investigating the relationship between emotional memory performance and the structural integrity of brain regions as well as the WM tracts connecting them could help in gaining a more comprehensive view of the neuroanatomical correlates of emotional memory in normal aging.

The first step in the present work was to establish norms for the affective properties of the Finnish nouns to be used in the subsequent studies. Previous normative databases for the affective properties of stimuli include the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), the Affective Norms for English Words (ANEW; Bradley & Lang, 1999, 2017), and the Discrete Emotion Norms for Nouns - Berlin Affective Word List (DENN-BAWL; Briesemeister, Kuchinke, & Jacob, 2011). However, these cannot be used universally, because it has been shown that the semantic and affective properties of words are language- and even culture-specific (e.g., Eilola & Havelka, 2010; Redondo, Fraga, Padrón, & Comesaña, 2007; Soares, Comesaña, Pinheiro, Simões, & Frade, 2012). Also, an individual's appraisal of the emotion-eliciting situation (here a word) plays a major role. For example, the evaluation of the affective properties of words may differ depending on the prevailing cultural norms during the socialization period of the emoter or individual (Scarantino, 2016). Cultural norms are usually representative of their time in history, from which follows that they may vary for different generations or age cohorts (Settersten & Godlewski, 2016). They may also differ for men and women. In fact, there is evidence to suggest that demographic characteristics such as age (e.g., Fairfield, Ambrosini, Mammarella, & Montefinese, 2017; Gilet, Grühn, Studer, & Labouvie-Vief, 2012; Grühn & Smith, 2008; Grunwald et al., 1999; Keil & Freund, 2009) and gender (e.g., Bellezza, Greenwald, & Banaji, 1986; Grunwald et al., 1999; Soares et al., 2012; Warriner, Kuperman, & Brysbaert, 2013) indeed affect the valence and arousal ratings of words. Therefore, in the interest of achieving an optimal level of experimental control over the valence and arousal levels of these word stimuli, an additional goal of the present thesis was to study possible age- and gender-related differences in the evaluations of these words.

1.1. Evaluating the affective properties of words

1.1.1. The relationship between valence and arousal in word databases

The emotional enhancement effect has been shown irrespective of modality or stimulus type (e.g., Kousta, Vinson, & Vigliocco, 2009; Plichta et al., 2011; Schaefer, Pottage, & Rickart, 2011). However, words hold advantages as experimental materials, because they are easy to present and permit experimental control of several objective psycholinguistic measures known to affect cognitive processing, such as word frequency (Adelman & Estes, 2013; Cortese, Khanna, & Hacker, 2010; Diana & Reder, 2006) and length (Adelman & Estes, 2013; Cortese et al., 2010; Tehan & Tolan, 2007). Several databases containing norms for valence and arousal ratings of words have been created, the first of which was ANEW in 1999 (Bradley & Lang, 1999, 2017). Thereafter, databases, some of which are translations of ANEW, have emerged in many languages (e.g., Eilola & Havelka, 2010; Gilet et al., 2012; Grühn & Smith, 2008; Monnier & Syssau, 2014; Redondo et al., 2007; Soares et al., 2012). There are also databases for researchers employing the categorical account of the structure and nature of emotion, such as DENN-BAWL (Briesemeister et al., 2011), and even for those combining the dimensional and the categorical accounts, the Madrid Affective Database for Spanish (MADS; Hinojosa et al., 2016). Separate norms for men and women are commonly offered (e.g., Redondo et al., 2007; Warriner et al., 2013), but age-specific norms are scarce (Fairfield et al., 2017; Warriner et al., 2013).

To depict the relationship between the dimensions of valence and arousal, the bivariate distribution of ratings on these dimensions is plotted in a two-dimensional space, also called the *affective space*. The distribution has usually shown a curvilinear shape with a predominantly quadratic trend (e.g., Bradley & Lang, 1999, 2017; Eilola & Havelka, 2010; Ferré, Guasch, Moldovan, & Sánchez-Casas, 2012; Hinojosa et al., 2016; Kanske & Kotz, 2010; Monnier & Syssau, 2014; Montefinese, Ambrosini, Fairfield, & Mammarella, 2014; Redondo et al., 2007; Soares et al., 2012; Warriner et al., 2013). Stimuli that are rated high in either positive or negative valence also elicit high arousal ratings, whereas stimuli rated as neutral in valence elicit low arousal ratings. This propensity to perceive highly valenced stimuli as highly arousing probably reflects the engagement of one of two motivational psychobiological subsystems (Bradley, 2000; Bradley & Lang, 2000). The appetitive/positive system helps the organism attain objects favorable to survival, and the aversive/negative system aims at reacting to threat or danger (Bradley, 2000; Bradley & Lang, 2000). According to this theory, the level of arousal reflects the strength of system activation and degree of required effort for the response. Hence, in very positive or negative events, maximal effort is required, but in response to neutral stimuli, the activation level is low (Kuppens, Tuerlinckx, Russell, & Barrett, 2013). However, the clear curvilinear shape has been evident in studies using young adult raters, whereas the results for older adults are varied. Warriner et al. (2013) reported the curvilinear shape also when older adult raters were included, whereas other studies have shown an increasingly linear relationship between valence and arousal ratings (Fairfield et al., 2017; Keil & Freund, 2009). In particular, the association between valence and arousal ratings for positive words has decreased and the association for negative words increased for older adults (Fairfield et al., 2017; Keil & Freund, 2009).

1.1.2. Age differences in the evaluation of emotional word content

In psychological terms, differences in the evaluation of emotional content in stimuli are thought to reflect differences in general emotion perception and emotional experience. Emotional experience has been shown to become more differentiated, leading to a more nuanced emotional life later in the lifespan (Schneider & Stone, 2015). Also, the positivity effect has surfaced both in emotion perception (Grunwald et al., 1999) and in emotional experience (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles, Reynolds, & Gatz, 2001; Mroczek & Kolarz, 1998). As regards self-reported affect, a reduced negativity bias in older age has been consistently reported (e.g., Carstensen et al., 2000; Charles et al., 2001; Mroczek & Kolarz, 1998), but the positivity bias has surfaced inconsistently (e.g., Mroczek & Kolarz, 1998). The reduction in subjective negative affect seems to level out after age 60 (Carstensen et al., 2000; Charles et al., 2001). It could be expected, then, that the positivity effect would emerge in valence ratings of stimuli as well, but the evidence to that effect is mixed (Fairfield et al., 2017; Gilet et al., 2012; Grühn & Smith, 2008; Keil & Freund, 2009; Warriner et al., 2013). The inconsistent results are probably due to methodological differences between the studies. Some studies have examined the differences between only two age groups (Fairfield et al., 2017; Grühn & Smith, 2008; Warriner et al., 2013), whereas other studies included a third group of middle-aged adults (Gilet et al., 2012; Keil & Freund, 2009). Furthermore, the studies have used different age ranges to create the age groups. Finally, the rating scales, the number of stimulus words, and the word class they represent have varied.

Older adults' arousal ratings of stimuli are assumed to be affected by their reported difficulties in coping with high levels of physiological and emotional arousal (e.g., Duffy, 1957), and in inhibiting processing of high-arousing material (Wurm, Labouvie-Vief, Aycock, Rebucal, & Koch, 2004). These age differences have been shown for perceived intensity of emotional experience (Carstensen et al., 2000; Diener, Sandvik, & Larsen, 1985; Lawton, Kleban, Rajagopal, & Dean, 1992; Wurm et al., 2004) as well as physiological arousal (Duffy, 1957). Generally, older adults have reported experiencing less intense emotion than young adults (Diener et al., 1985; Lawton et al., 1992), but variable results have been obtained regarding perceived intensity of the immediate emotional response to an event (e.g., Carstensen et al., 2000). Therefore, it is hardly surprising that studies on age differences in arousal ratings of words have also yielded inconsistent results (Fairfield et al., 2017; Gilet et al., 2012; Warriner et al., 2013), also pertaining to the arousal ratings for different word valence categories (Grühn & Smith, 2008; Grunwald et al., 1999; Keil & Freund, 2009). In addition to the methodological differences mentioned above, the variable findings may reflect the different conceptualizations of the arousal scale in these studies. Taken together, it is clear that further systematic studies are needed to examine age-specific effects in ratings of emotional content.

1.1.3. Gender differences in the evaluation of emotional word content

In emotion perception and emotional experience research, the majority of findings have indicated that women show an advantage in emotional processing skills to men, and a higher level of emotional reactivity and receptivity than men (Carstensen et al., 2000; Diener et al., 1985; Grunwald et al., 1999; Mroczek & Kolarz, 1998; Myers & Diener, 1995; Schneider & Stone, 2015). However, there are also contradictory findings (Charles et al., 2001; Mroczek & Kolarz, 1998; Schneider & Stone, 2015). Processing of negative emotions seems to give rise to more consistent gender differences (Bradley, Codispoti, Cuthbert, & Lang, 2001; Thomsen, Mehlsen, Viidik, Sommerlund, & Zachariae, 2005), but all in all, an argument could be made that there is gender-specificity regarding preference for positive and negative material (for a review, see Stevens & Hamann, 2012). Women seem to exhibit a preference for negative stimuli, and men for positive stimuli. The preference for negative stimuli in women may be a result of an interaction between the perceived level of arousal in negative stimuli and a stronger reactivity to emotion-laden stimuli. In general, negative stimuli would seem to evoke stronger general reactivity in terms of high arousal compared to positive or neutral stimuli (see Hamann, 2003; Keil & Freund, 2009). Women usually report feeling more intense emotions (e.g., Carstensen et al., 2000; Diener et al., 1985) and reactions to ongoing events (e.g., Myers & Diener, 1995). Furthermore, the strength and loci of neural responses to negative emotions also seem to differ for women and men (Stevens & Hamann, 2012).

However, there has been inconsistent support for gender-specificity in valence ratings of words. In partial support for a male preference for positive stimuli, several studies have reported that men give more positive mean ratings than women (Bellezza et al., 1986; Hinojosa et al., 2016; Monnier & Syssau, 2014; Warriner et al., 2013). However, some studies have found no gender difference in mean valence ratings (Gilet et al., 2012; Redondo et al., 2007). In support of a stronger general reactivity to emotion-laden stimuli in women, women have given more extreme valence ratings at both ends of the scale compared to men (Bellezza et al., 1986; Monnier & Syssau, 2014; Soares et al., 2012).

Again, mixed results prevail regarding more intense reactions in terms of arousal ratings to stimuli in women. Supporting the idea of a stronger female reactivity to emotional stimuli, women have given higher mean arousal ratings than men overall (Montefinese et al., 2014; Soares et al., 2012), or for valenced stimuli only, either for the negative ones (Grunwald et al., 1999) or for the positive ones (Monnier & Syssau, 2014). However, the reverse has also been reported (Warriner et al., 2013). Furthermore, null findings for gender differences in arousal ratings have also been reported in several studies (Gilet et al., 2012; Hinojosa et al., 2016; Redondo et al., 2007). Methodological differences do not offer equally convenient explanations for the conflicting results regarding gender differences in affective word ratings as they do for the conflicting results on age-related effects. For example, both Soares et al. (2012) and Redondo et al. (2007) used translations of the ANEW stimuli and the Self-Assessment Manikin (SAM) scales (Bradley & Lang, 1994). The only methodological difference between these studies lies in the number of words rated by each respondent.

1.2. Memory for emotion-laden words in normal aging

1.2.1. Cognitive and neural mechanisms for valence and arousal effects on memory

The vast neural network underlying EEM seems to be principally involved in linking emotions to stimulus events (Allen, Kaut, & Lord, 2008). According to the evolutionary perspective, the preferential processing of emotion-laden stimuli stems from neural circuits that have evolved to ensure the survival of the organism and its genes (Lang & Bradley, 2010). The survival/adaptive function of episodic memory would lie in the fact that the level of adaptive functioning in the environment is enhanced by our ability to use memory for specific events from the past (specifically their emotional salience) to guide present and future behavior (for reviews, see Allen et al., 2008; Dolan, 2002; Hamann, 2001). By contrast, a phenomenological perspective would hold that episodic memory, and especially memory for emotion-laden events, provides us with a sense of continuity, and awareness of personal history, thus moulding our personality and sense of self (Kandel, 2006). The EEM network is typically thought to encompass the amygdalae, the hippocampi, the medial and lateral prefrontal cortices (PFC), and the basal ganglia (Allen et al., 2008), all of which are extensively interconnected (Ghashghaei, Hilgetag, & Barbas, 2006; Price, 2003), with links to the sensory cortices (Amaral, Behniea, & Kelly, 2003; Price, 2003). While the structure and function of this network need to be elucidated in more detail, it is clear that the brain areas implicated in processing emotion-laden information are engaged also in processing other types of information (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Pessoa, 2008).

Table 1 presents an overview of the neural substrates and cognitive mechanisms for the effects of valence and arousal on memory. The contribution of *arousal* to EEM is thought to entail a “boost” in memory vividness through bottom-up automatic processing (e.g., Comblain et al., 2004; Kensinger & Corkin, 2003; Ochsner, 2000). However, corresponding enhancement in memory accuracy for arousing events or stimuli has not been observed (e.g., Adelman & Estes, 2013; Mickley

& Kensinger, 2009). Arousing memories are prone to distortion, in some studies even to the same degree as non-arousing memories are (Kensinger & Schacter, 2016). In their review, Kensinger and Schacter (2016) concluded that arousal results in selective memory benefits for some details of the event, but that there is no consensus as to which specific details would be remembered better. Furthermore, enhanced memory accuracy for arousing stimuli is associated with simultaneous liberal response bias for these stimuli (Comblain et al., 2004). Therefore, the seemingly augmented memory for high-arousing stimuli may in fact reflect a stronger general tendency to endorse these stimuli as 'old'.

Table 1

Overview of Neural Substrates and Cognitive Mechanisms for the Contributions of Valence and Arousal to Memory

Affective dimension	Neural substrate	Processing mode	Effect on memory	Task-specific function
Arousal	Medial temporal lobe (MTL)-based network	Automatic, bottom-up	Memory vividness, selective memory accuracy for some details	
	Central structure: Amygdalae	Automatic, bottom-up (or activity as a result of top-down PFC modulation?)	Increased attention and elaboration during encoding, enhancing consolidation, providing retrieval cue as part of contextual information	Modulation of activity in other brain areas by enhancing processing of information with survival value
Valence	Non-MTL network	Controlled, top-down	Memory accuracy (negative: for detail; positive: for contextual information) Negative: memory vividness	Augmentation of executive, attentional, and semantic processes
	Central structure: Prefrontal cortex (PFC)	Controlled, top-down		
	Orbitofrontal cortex (OFC)			Integration of exteroceptive and interoceptive information to regulate behavior
	OFC, medial PFC			Processing of stimulus value and computation of outcome expectancies
	Ventromedial, dorsomedial PFC			Detection of self-relevant stimuli and self-reflection
	(Dorso)lateral PFC			Cognitive control of emotion via goal-directed response selection, explicit stimulus evaluation, working memory, and attentional control; setting priorities according to subjective individual goals

The *arousal-driven* bottom-up automatic processing with its resulting contribution to EEM is thought to be based on neurohormonal interactions within a medial temporal lobe (MTL)-based network, involving the amygdalae and various memory-related areas (for a review, see Dolcos et al., 2017). Within the MTL-based network, the amygdalae hold a central role in bringing about enhanced vividness and detail in memory for emotionally arousing stimuli (Dolcos et al., 2017; Kensinger & Corkin, 2004; Kensinger & Schacter, 2016) regardless of their valence (Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000). According to the memory modulation hypothesis by McGaugh (2000), the principal function of amygdalar activation is to augment processing of information with survival value. This is achieved by modulating the activity in other brain areas specifically via the adrenergic system (e.g., Dolan, 2002; Hamann, 2001; Kensinger & Corkin, 2004; McGaugh, 2000). The modulation is enabled by the extensive anatomical connectivity of the amygdalae with several brain areas, such as the orbitofrontal cortex (OFC), the anterior cingulate cortex (ACC), the ventral striatum, the hippocampi, and the occipital cortex (Amaral et al., 2003; Dolan, 2002; Hamann, 2001; Kensinger & Corkin, 2004; Ghashghaei et al., 2007; Price, 2003). Amygdalar modulation of the activity of the hippocampal formation during memory encoding of emotion-laden events and stimuli is seen as imperative for memory consolidation to occur (Adolphs et al., 1997; Hamann, 2001; McGaugh, 2000). Interestingly, there is a strong positive correlation between amygdalar activation level during encoding and later memory vividness (Kensinger, Addis, & Atapattu, 2011). Amygdalar activation is not exclusive to the encoding phase (Canli et al., 1999; Fischer et al., 2010; Hamann et al., 1999; Kensinger & Corkin, 2004; Kensinger & Schacter, 2016; Tabert et al., 2001), as it has also been observed during retrieval of emotion-laden stimuli (Dolan et al., 2000; Dolcos, LaBar, & Cabeza, 2005), even after a one-year retention interval between encoding and retrieval (Dolcos et al., 2005). The role of the amygdalae in mediating EEM may thus extend from providing increased attention and elaboration to emotion-laden stimuli during encoding, to enhancing the consolidation of memory traces (Hamann, 2001). Alternatively, the retrieval-related activation may constitute a part of the contextual information associated with a stimulus, which then operates as a cue for the successful retrieval of that stimulus (Allen et al., 2008). Interestingly, arousal seems to induce carry-over effects that entail enhanced memory accuracy and vividness for neutral stimuli that have been incidentally encoded after prolonged initial exposure to negative and arousing pictures (Tambini, Rimmele, Phelps, & Davachi, 2017). These observed carry-over effects indicate that a sustained emotion-related brain state can affect memory consolidation also for emotionally neutral material. However, it should be emphasized that the amygdalae should not be misconstrued as the loci of EEM, as the enhancement effect in itself is assumed to occur within or be mediated by the hippocampi (McGaugh, 2000). Furthermore, it should be pointed out that the relatively slow development of the hemodynamic response is an inherent confound in the study of amygdalar activation during emotional processing (Pollock, Khoja, Kaut, Lien, & Allen, 2012). Thus, it is questionable whether the amygdalar activation that has been measured in functional magnetic resonance imaging (MRI) reflects bottom-up arousal-driven modulation via the visual cortex at all. Instead, it has been suggested to reflect top-down modulation by prefrontal mechanisms (Pollock et al., 2012).

Valence is thought to contribute to EEM by enhancing memory accuracy through top-down controlled processing (Adelman & Estes, 2013; Charles et al., 2003; Comblain et al., 2004; Wang & Yang, 2017), but the effect of valence polarity (positive-negative) appears to be at least partly dependent on stimulus type. Memory for negative stimuli, such as pictures or words, tends to be better than memory for positive stimuli (Adelman & Estes, 2013; Comblain et al., 2004; Leal, Noche, Murray, & Yassa, 2016; Ochsner, 2000). This seems to be related to a liberal response bias for negative stimuli in some studies (Adelman & Estes, 2013; Ochsner, 2000). Memory for positive autobiographical events or information encoded in reference to the self tends to prevail over memory for negative ones (for a review, see Kensinger & Schacter, 2016). This has been thought to reflect goal-relevance of the emotion-laden information at hand (e.g., Kensinger & Schacter, 2016; LeDoux, 1996). For survival, it may be most relevant to remember negative stimuli (LeDoux, 1996), but if the goal is to create an adaptive self-concept, it may be more beneficial to remember positive life experiences (Kensinger & Schacter, 2016). In fact, in the face of these possible interactions between stimulus or event valence and differences in self-relevance and/or congruency with individual motivational goals or state, it is currently debated whether the effects of valence on memory would be better explained as effects of *factors related to* valence rather than as effects of valence itself (Kensinger & Schacter, 2016). Still, just as in the case of arousal, the valence of the affective response to a stimulus may affect qualitative aspects of memory. Negative affect can bring a narrowing of attention to stimulus details (e.g., Waring & Kensinger, 2009), as opposed to positive affect that leads to an increased reliance on gist-based information (see Fredrickson, 2004, for the associated "broaden-and--build" theory of positive affect; Kensinger & Schacter, 2016; but see Leal et al., 2016). Consequently, negative stimuli often elicit a stronger sense of vividness than positive stimuli (e.g., Comblain et al., 2004; Ochsner, 2000). However, this may also reflect the interrelatedness between valence and arousal whereby negative stimuli tend to be perceived as more arousing than positive stimuli (e.g., Hamann, 2003; Rozin & Royzman, 2001).

The *valence-driven* top-down controlled processing that results in EEM via the augmentation of executive, attentional, and semantic processes is thought to rely on the activation of a mainly cortical non-MTL network (Dolcos et al., 2017). Within the non-MTL network, the PFC has particular significance for EEM (Dolcos et al., 2017), although there seems to be valence-specificity in the cortical brain activation patterns during encoding of emotion-laden stimuli (Kensinger & Schacter, 2016). Moreover, differential recruitment within the hippocampal system has been observed during retrieval of positive and negative events (Ford et al., 2014). Several prefrontal areas are thought to make functionally specific contributions to EEM (Adolphs, 2009; Canli et al., 1999; Champod & Petrides, 2007; Corbetta, Patel, & Schulman, 2008; Dolan et al., 2000; Fischer et al., 2010; Fossati, 2012; Hamann et al., 1999; Herold, Spengler, Sajonz, Usnich, & Bermpohl, 2016; Kensinger & Corkin, 2004; Lindquist et al., 2012; MacDonald, Cohen, Stenger, & Carter, 2000; Miller & Cohen, 2001; Ochsner & Gross, 2005; Ochsner, Silvers, & Buhle, 2012; Pessoa, 2008; Schmitz & Johnson, 2007). These areas mainly encompass the OFC and the ventromedial PFC (Pessoa, 2008), but also the dorsolateral PFC (Adolphs, 2009; Ochsner & Gross, 2005). The ventromedial PFC includes the medial OFC and the ventral and rostral ACC (Fossati, 2012). Just as the amygdalae, prefrontal brain areas exhibit strong reciprocal connectivity with virtually every sensory system, with cortical and subcortical motor systems, and with limbic and midbrain structures involved in memory and emotion (Miller & Cohen, 2001). Therefore, the PFC receives highly processed and integrated information for further processing at a more abstract level (Pessoa, 2008). Furthermore, extensive interconnectivity also exists between the various PFC areas themselves (Miller & Cohen, 2001), which enables conjoint engagement (Miller & Cohen, 2001; Ochsner & Gross, 2005; Schmitz & Johnson, 2007), or control of the responses of other PFC areas (Fossati, 2012; Pessoa, 2008). The specific contributions of the various PFC regions to EEM can be seen in Table 1.

1.2.2. Memory for emotion-laden stimuli in the aging brain

As previously stated, relatively few functional neuroimaging studies have been devoted to identifying the neural substrates of memory for emotion-laden stimuli in cognitively intact middle-aged and older adults (e.g., Addis et al., 2010; Fischer et al., 2010; Ford & Kensinger, 2017; Kensinger & Schacter, 2008; Leal, Noche, Murray, & Yassa, 2017). The studies comparing young and older adult groups have yielded variable results. For example, Fischer et al. (2010) found no age differences in left amygdalar activation, but attenuated activity in the right amygdala and both hippocampi in older adults compared to young adults during successful incidental encoding of fearful faces. Kensinger and Schacter (2008) found no age differences in the recruitment of the amygdala and OFC, while activation strength in a PFC-temporal lobe network varied between young and older adults during successful encoding of positive stimuli. Interestingly, age-specific differential recruitment of ventral and more dorsal PFC areas was observed during retrieval of negative vs. positive images depending on subjective memory vividness, possibly reflecting that older adults engage in emotion regulation during retrieval of negative events (Ford & Kensinger, 2017). Studies on age differences in functional brain connectivity patterns have yielded inconsistent results (Addis et al., 2010; Ford et al., 2014; St Jacques et al., 2009), but a common feature seems to be that only older adults engage PFC areas that have been implicated in cognitive control and self-referential processing (Reed et al., 2014). These systems have been hypothesized to drive the positivity effect in memory (e.g., Kensinger, 2008; Mather, 2012; Ngo, Sands, & Isaacowitz, 2016; Reed et al., 2014). Thus, the observed age differences in memory for emotion-laden stimuli may, indeed, be mirrored in concomitant age-related changes in brain activation and connectivity patterns for EEM and the positivity effect in memory.

Studies with the aim of delineating regional GM volumetric and WM microstructural correlates of emotional memory in cognitively intact middle-aged and older adults have also been scant. Investigations of the neural underpinnings of emotional memory in this age segment nevertheless holds promise in light of the individual variability in structural brain changes in EEM-related regions that may accompany normal aging. Regarding amygdalar volume, some cross-sectional studies have found no significant reductions across lifespan compared to other brain structures (e.g., Jernigan et al., 2001). Others have found less marked age-related changes in amygdalar volume compared to other brain regions (e.g., Grieve et al., 2005; Kalpouzos et al., 2009). Still others have reported clear negative associations with age (e.g., Allen, Bruss, Brown, & Damasio, 2005; Fjell et al., 2013). Mixed findings prevail in longitudinal studies as well (e.g., Fjell et al., 2013; Frodl et al., 2008; Pressman et al., 2016). Taken together, age-related decline in amygdalar volume seems to be less notable than that found in other regions, such as the hippocampi (Mather, 2016). For hippocampal volume, some cross-sectional studies have reported no significant decline in hippocampal volume over the lifespan (Grieve et al., 2005; Kalpouzos et al., 2009), whereas others have found age-related hippocampal volume reduction (Jernigan et al., 2001). The inconsistency may reflect non-linearity of hippocampal volume reduction with age, as reduction (Allen et al., 2005) or an accelerated rate of decline (Fjell et al., 2013; Jernigan et al., 2001) has generally been observed in the older age segments, starting at age 60. Longitudinal studies also report a tendency for hippocampal GM volume to start declining only late in life (e.g., Fjell et al., 2013). By comparison, normal aging has consistently been shown to entail particularly pronounced GM volume decline in the frontal lobe (e.g., Allen et al., 2005; Grieve et al., 2005; Jernigan et al., 2001; Kalpouzos et al., 2009). Intriguingly, Mather (2016) suggested that the pattern of age-related GM volume decline in different areas of the frontal lobe (e.g., Fjell & Walhovd, 2010;

Grieve et al., 2005) would mirror the "paradox of aging" with simultaneous age-related deterioration of dorsolateral PFC-driven cognitive functions (Nyberg et al., 2012) and preserved functioning in ventromedial PFC-driven socioaffective domains (Mather, 2016). However, in a study designed to directly compare volume changes in brain regions primarily associated with cognitive processing vs. those primarily linked to emotional processing in healthy participants aged 60 to 100 years, no significant differences in volume change between "cognition-related" or "emotion-related" brain areas as a whole were found (Pressman et al., 2016). Still, differential rates of decline were demonstrated for the various regions within these two broad brain areas. Previous studies on the relationships between brain structural measures and emotional memory performance in normal aging have typically favored a region-of-interest (ROI) approach (Ford & Kensinger, 2014; Guzmán-Vélez, Warren, Feinstein, Bruss, & Tranel, 2015; Landré et al., 2013; Schultz, de Castro, & Bertolucci, 2009; Yau et al., 2009). Most of the studies on regional GM correlates have focused on the amygdalae and the hippocampi and used quite small samples (Guzmán-Vélez et al., 2015; Landré et al., 2013; Schultz et al., 2009). Whole brain volumetric correlates have been investigated using mixed groups of normally aged adult controls and patients suffering from amnestic mild cognitive impairment (Mistridis et al., 2014), Alzheimer's disease (Kumfor, Irish, Hodges, & Piguet, 2013, 2014; Mistridis et al., 2014), and variants of frontotemporal dementia (Kumfor et al., 2013, 2014).

Previous work has found no associations between amygdalar volume and memory for emotion-laden stimuli in healthy middle-aged and older adults (Guzmán-Vélez et al., 2016; Landré et al., 2013; Schultz et al., 2009). Regarding hippocampal volumetric associations, better memory for emotion-laden stimuli has been correlated with larger hippocampal volume in normal aging (Guzmán-Vélez et al., 2016), albeit not consistently (Landré et al., 2013; Schultz et al., 2009). Similarly, studies on hippocampal volumetric associations with memory for emotionally neutral stimuli have yielded mixed results (Landré et al., 2013; Schultz et al., 2009). Whole brain volumetric studies using combined groups of patients with neurodegenerative disorders and normally aged controls have revealed positive correlations between local GM volume in the OFC and ventromedial and ventrolateral PFC and memory for negative stimuli (Kumfor et al., 2013; Mistridis et al., 2014). Mistridis et al. (2014) found that immediate free recall of positive words was associated with GM volume in one cluster centered in the left angular gyrus, extending into the middle temporal gyrus. Delayed free recall of positive words was related to GM volume in a cluster centered in the left hippocampus, extending into the amygdala, the entorhinal, perirhinal, and parahippocampal cortices, and the lingual gyrus (Mistridis et al., 2014).

Similarly as for changes in the structural integrity reflected by GM volume, changes in WM microstructural properties have been observed over the lifespan of healthy individuals. FA levels exhibit a rapid increase in early development, reaching a plateau during middle adulthood, and then start to decrease after age 60 (e.g., Lebel et al., 2012; Salat et al., 2009). The general pattern of change follows an anterior-to-posterior gradient, such that the age-related changes are more pronounced in anterior (frontal and parietal) WM tracts relative to posterior WM tracts, with the caveat of variability within anterior and posterior regions (for a review, see Salat et al., 2009). There is evidence of heterogeneity in the age-related pattern of FA levels also within WM tracts (Mårtensson et al., 2018). It is yet to be determined which neurobiological tissue characteristics drive the effects of normal age-related changes in WM microstructural properties (Bender & Raz, 2015). Structural WM connectivity correlates of memory for emotion-laden stimuli in healthy aging are still poorly known (Ford & Kensinger, 2014; Yau et al., 2009). A larger body of research exists on these correlates of emotionally neutral memory (e.g., Bennett & Madden, 2014; Charlton, Barrick, Markus, & Morris, 2013; Henson et al., 2016; Lockhart et al., 2012). In a multimodal neural connectivity study, the neural correlates of memory for neutral titles of emotion-laden images were studied in 19-85-year-old adults, but not structural connectivity correlates of emotion-laden stimuli as such (Ford & Kensinger, 2014). In this study, age was associated with structural and functional connectivity between the amygdala and the ventral PFC, varying as a function of valence. In another study, the association between temporal stem FA and negative story recall was examined in a combined group of older Type II diabetics and healthy controls (Yau et al., 2009). Higher temporal stem FA was significantly related to higher immediate recall of the negative story, but not to delayed recall.

1.2.3. Theories on the underlying mechanisms of the age-related positivity effect

The existence of the age-related positivity effect, or the age-related change in valence-specific preferences in cognition has been debated, because it has not emerged consistently (e.g., Mather & Carstensen, 2005; Reed & Carstensen, 2012; Reed et al., 2014). Here the main theoretical models that attempt to describe the mechanisms that drive the positivity effect will be presented (for reviews, see Charles & Hong, 2016; Ngo et al., 2016). Table 2 gives an overview of the main theories, the main counterarguments, and their predictions for the effect of arousal (see Chapter 1.2.4.).

Table 2

Overview of the Main Theories on the Age-Related Positivity Effect and Their Predictions for the Effect of Arousal

			Arousal	
Theory	Driving mechanism	Main counterargument	Level	Prediction
Socioemotional Selectivity Theory (SST; Carstensen, Isaacowitz, & Charles, 1999)	Motivational shift in the face of increasingly constrained time perspective			
SST extension: Cognitive Control Model (CCM; Mather, 2012)	Cognitive control for the purpose of emotion regulation	Age-related decline in cognitive control efficiency and related neural substrates (for reviews, see e.g., Mather, 2016; Reed & Carstensen, 2012)	Low	Young adults: negativity bias Older adults: positivity bias
			High	No age x valence interaction
Dynamic Integration Theory (DIT; Labouvie-Vief, 2003; Labouvie-Vief, Grühn, & Studer, 2010)	Age-related neurocognitive decline that disables processing/integration of complex affective information	Positivity effect exhibited in older adults high in cognitive control (Mather & Knight, 2005)	Low	Older adults > young adults, esp. positive stimuli Young adults: no negativity bias
			High	Young adults > older adults, esp. negative stimuli

The dominant theory is the Cognitive Control Model (CCM; Mather, 2012; Ngo et al., 2016), which is an extension of the Socioemotional Selectivity Theory (SST; Carstensen, Isaacowitz, & Charles, 1999; Ngo et al., 2016). SST is a lifespan theory on motivation, according to which increasing age entails shifts in the priorities of implicit goals because of an increasingly constrained time perspective (Carstensen, 1995). With an increasingly stronger sense that future time left in life is limited, goals associated with emotional meaning and current well-being gain importance, whereas goals associated with preparation for the future, such as securing survival by acquiring knowledge and experiencing novelty, become less salient (Carstensen, 1995; Mather & Carstensen, 2005; for a recent review, see Reed & Carstensen, 2012; Ngo et al., 2016). A stronger investment in emotional goals promotes emotion regulation (Carstensen, 1995; Mather & Carstensen, 2005; Reed & Carstensen, 2012), which is defined as maintaining positive affect while decreasing negative affect (Charles et al., 2003). Therefore, the positivity effect would be a consequence of higher spontaneous resource allocation with advancing age towards emotion regulation (Mather & Carstensen, 2005). This requires cognitive control and absence of situation-specific goals that would supersede the constantly activated implicit goals (Reed et al., 2014). According to the CCM/SST framework, the basic mechanism underlying the positivity effect would therefore entail the engagement of self-directed cognitive control functions aiming at producing goal-congruent – and therefore self-relevant - behavior (Mather & Carstensen, 2005; Reed et al., 2014). The implicit future-oriented goal in young adulthood would be attained by attending to and remembering negative information (Reed et al., 2014). In middle and older adulthood, upholding present emotional well-being would be achieved by diverting attention away from negative information and even by preferring positive information (Reed et al., 2014). This would be consistent with the idea that valence evokes controlled, primarily frontally mediated processing. However, the main argument against the CCM/SST explanation for the positivity effect is that emotional regulation is resource-demanding and therefore taxes prefrontal functions (Adolphs, 2009; MacDonald et al., 2000; Ochsner & Gross, 2005; Ochsner et al., 2012) subject to age-related decline (Mather, 2016). Furthermore, advancing age entails decreased efficiency of cognitive control (Mather & Carstensen, 2005; Reed & Carstensen, 2012). The seminal study by Mather and Knight (2005) showed that the positivity bias in memory surfaced only for older adults with high levels of cognitive control, whereas those with low levels of cognitive control exhibited a negativity bias akin to that of the young adults. Mather and Knight (2005) also offered evidence that the availability of relatively abundant and undivided cognitive resources may be a prerequisite for the emergence of the positivity effect, which was corroborated in a recent meta-analysis (Reed et al., 2014). Reed et al. (2014) demonstrated that the positivity bias in older adults surfaced only in studies employing naturalistic and unconstrained experimental designs, such as incidental as opposed to intentional encoding paradigms. Support for CCM/SST is also found in studies demonstrating age differences in brain activation patterns during emotional memory processing (for reviews, see Dolcos et al., 2017; Kensinger & Gutchess, 2017). Furthermore, older adults seem to favor emotional regulation strategies that are less cognitively demanding and that recruit brain areas exhibiting relatively small age differences in functional efficiency (for a review, see Mather, 2016).

Some theories advance the more pessimistic notion that structural and functional brain changes underlie age differences in emotional memory. The most influential one is Dynamic Integration Theory (DIT; Labouvie-Vief, 2003; Labouvie-Vief, Grühn, & Studer, 2010; Ngo et al., 2016), which posits that the observed changes in cognition-emotion interaction result from age-related neurocognitive decline (Ngo et al., 2016). According to DIT, the preference for positive information or the avoidance / diverting attention from negative information in older adults is due to lack of cognitive resources for effective processing of complex affective information (Labouvie-Vief, 2003; Labouvie-Vief et al., 2010; Ngo et al., 2016). During the development into adulthood, an individual practices in integrating both positive and negative features of different events to gain a more complex representation of a situation, ultimately leading to a higher tolerance of distress evoked by challenging events (Charles & Hong, 2016; Ngo et al., 2016). This view stems from the basic idea that a biological organism always strives for equilibrium, homeostasis, through tension reduction. Tension comes from negative affective states and as tension is minimized, rewarding positive emotions arise (Ngo et al., 2016). As a result of the cognitive decline that accompanies aging, older adults have an increased tendency to become overwhelmed in such situations, leading to a propensity to avoid them (Labouvie-Vief, 2003; Labouvie-Vief et al., 2010; Ngo et al., 2016). This propensity involves reverting to the automatic emotion regulation strategy of affect optimization, which entails using cognitive processes to maximize positive affect and minimize negative affect. This stands in contrast to the controlled, effortful regulation strategy of affect differentiation, or integration of positive and negative affect (Labouvie-Vief, 2003; Labouvie-Vief et al., 2010). At the neurobiological level, the hypothesized mechanism underlying this development in emotion-regulatory skills over time is the increasing – and later declining - connectivity between the PFC and other brain regions (Ngo et al., 2016).[1]

So far, empirical support seems to favor the CCM/SST account over the other theories (but see Foster, Davis, & Kisley, 2013 for evidence to the contrary in older adults). For example, DIT cannot explain why older adults with higher levels of cognitive control tend to exhibit the positivity bias (Mather & Knight, 2005), as DIT would predict that older adults with lower levels of cognitive control would demonstrate this effect (Ngo et al., 2016). Also, a recent study seemed to offer evidence favoring SST over the decline-based DIT and ABM accounts, but no account received full support (Kalenzaga, Lamidey, Ergis, Clarys, & Piolino, 2016). In this study, young adults, older adults, very old adults, and patients with Alzheimer's disease were to intentionally learn words varying in valence under no-encoding-strategy and semantic-

[1] Because the following theoretical frameworks were not used in direct hypothesis testing, they are only briefly described here. Another decline-based account, the Aging Brain Model (ABM; Cacioppo, Berntson, Bechara, Tranel, & Hawkley, 2011) holds that the positivity effect may arise from preserved amygdalar activation to positive stimuli in older age, while activation to negative stimuli is reduced (e.g., Gunning-Dixon et al., 2003), leading to dampened reactivity to arousal elicited by negative stimuli. In turn, this would entail a diminished memory benefit for emotionally arousing negative events (Cacioppo et al., 2011; Ngo et al., 2016). The theoretical model of Strength and Vulnerability Integration (SAVI; Charles, 2010; Charles & Hong, 2016) was developed to address contradictory findings on emotional wellbeing and emotion regulation in aging. It integrates SST and DIT, and acknowledges that aging entails both preservation and decline. When strengths, such as using attentional strategies to regulate emotional experiences, cannot be utilized, age-related vulnerabilities may result in greater difficulty to modulate physiological arousal (Charles, 2010). SAVI further states that the relationship between these aspects of aging is modified by individual differences and differences in life circumstances (Charles & Hong, 2016).

encoding-strategy conditions. For example, in line with CCM/SST, the positivity bias was most prominent for healthy older and very old adults in delayed free recall; however, it also emerged for young adults. Furthermore, in line with DIT/ABM but against CCM/SST, also the AD group exhibited a positivity bias in recognition memory, for words encoded in the semantic-encoding-strategy condition.

1.2.4. The role of arousal in the age-related positivity effect

The abovementioned theoretical accounts of the age-related positivity effect provide diverging predictions for the role of arousal, specifically at high arousal. An overview of the CCM/SST and DIT accounts and their predictions for the role of arousal in generating the age-related positivity effect in memory is provided in Table 2. CCM/SST posits that the valence-specific positivity effect is driven by controlled processing. Therefore, no age differences in valence-specificity in memory should emerge for *high-arousing stimuli*, as these stimuli evoke automatic processing. By contrast, DIT would predict worse memory for high-arousing stimuli in older adults, particularly for stimuli of negative valence, because of the age-related deterioration in the capacity to integrate complex emotion-laden information, and thus regulate affect when faced with such stimuli. As for *low-arousing stimuli*, CCM/SST would predict a positivity effect in memory with a negativity bias in young adults and a positivity bias in older adults. DIT would predict better memory in older adults for low-arousing stimuli irrespective of valence, but particularly for positively valenced ones, because of the low complexity of this stimulus type. Young adults should exhibit no negativity bias at low arousal.[2]

[2] ABM would yield the same predictions for memory for high-arousing stimuli, but because of its focus on age-related structural and functional brain changes in producing these effects, it will not be further elaborated upon in the present behavioral part of this thesis. SAVI has not been used to predict age differences in emotional memory performance. Tentatively, SAVI would predict that when high-arousing negative situations cannot be avoided, age differences in emotional well-being would attenuate or even disappear, because the (compensatory) strengths of aging could not be employed. Avoidance is achieved, for example, by diverting attention away from the stimuli causing emotional distress. If this line of argumentation is extended to memory

The previous findings on the role of arousal in producing the age-related positivity effect in memory have been variable. In her seminal study, Kensinger (2008) found that the age-related positivity effect emerged in memory accuracy specifically for low-arousing words, whereas EEM was seen in both age groups for high-arousing words. Later studies have not been able to replicate this finding. Some studies have found no interaction effects of either valence or arousal with age in memory (Comblain et al., 2004), whereas others have reported age-related effects in qualitatively different forms (Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). Several methodological issues may explain the variability of these results. For example, Comblain et al. (2004) did not examine possible interaction effects of valence and arousal on memory, but restricted their investigation to the unique effects of these stimulus characteristics. The studies on age-related interaction effects between valence and arousal on memory have all confined arousal to only two levels, low and high, and refrained from studying how arousal affects memory for emotionally neutral stimuli (Kensinger, 2008; Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). Also, the cut-off scores for the arousal levels have differed in these studies. Furthermore, none of the studies that have failed to replicate Kensinger's (2008) findings used word stimuli as she did, but a variable array of pictorial stimuli (Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009).

1.3. Aims and hypotheses

The general aim of the present thesis was to investigate the neurocognition of memory for emotion-laden words in healthy cognitive aging. Despite the fact that the processing advantage for emotional content is generic, generalizing across different experimental

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for emotion-laden stimuli, older adults should exhibit worse memory for high-arousing stimuli, specifically negative ones, which can potentially cause emotional distress. As SAVI incorporates SST (Charles, 2010; Charles & Hong, 2016), it could be contended that SAVI also would predict a positivity bias for low-arousing stimuli in older adults.

materials (e.g., Kousta et al., 2009; Schaefer et al., 2011), it is now known that emotional content is differentially processed in words as compared to, for example, pictures at both behavioral and neural levels (e.g., Hinojosa, Carretié, Valcárel, Méndez-Bértolo, & Pozo, 2009; Spaniol, Voss, & Grady, 2008). This is thought to reflect higher physiological arousal induced by pictorial stimuli because of their stronger biological relevance compared to words for which emotional meaning is learned (Hinojosa et al., 2009). As for the impact of stimulus type on age-related effects of emotion on memory, evidence is mixed with some behavioral studies showing age effects only for words (Leigland, Schulz, & Janowsky, 2004), others no stimulus type-dependent effect (Spaniol et al., 2008), and still others inconsistent stimulus type-dependent effects (Fernandes, Ross, Wiegand, & Schryer, 2008). At the neural level, it would seem that medial PFC activation is found for any kind of emotion-laden material, but with distinct patterns for negative and positive valence depending on stimulus type in older adults compared to young adults (for a review, see Mather 2016). In the present thesis, words were chosen as experimental materials, because episodic memory tasks with a word learning context have been shown to be sensitive to normal neurocognitive aging processes (e.g., Murphy, West, Armilio, Craik, & Stuss, 2007), and because there were no previous studies on neural correlates of successful memory encoding of emotional words in cognitively intact middle-aged and older adults at the time when this project was started. Also, as previously stated, words are easy to use and allow experimental control of several objective psycholinguistic features with known effects on cognitive processing (e.g., Adelman & Estes, 2013; Tehan & Tolan, 2007). The specific aims of the four studies were the following:

Study I. The first aim of the study was to create age- and gender-specific normative data for valence and arousal ratings for a set of 420 Finnish nouns, coupled with corpus-based frequency values. To date, no similar age- or gender-specific norms have been reported for Finnish nouns. The second aim was to describe the word ratings in this database in terms of (a) the distribution of the ratings in the affective space, (b) possible age and gender differences in mean valence and arousal ratings for all words and for words classified by their mean valence ratings, and (c) the relationships between the ratings in this study and the ratings in previous studies using the same words (Bradley & Lang, 1999, 2017; Eilola & Havelka, 2010; Redondo et al., 2007). In light of previous work using databases with lexical stimuli selected to represent the entire affective space (Fairfield et al., 2017; Keil & Freund, 2009), the introduction of older adult raters to the sample was expected to yield a less prominent quadratic trend than in previous studies, and a weaker association between valence and arousal ratings for positive words than for negative words. Previous work has shown that age and gender affect emotional processing, but the evidence regarding the effects of these demographic characteristics on valence and arousal ratings is mixed. Therefore, our predictions for these effects were largely tentative. As compared to younger adults, older raters were expected to give higher valence ratings for positive words, as well as higher mean arousal ratings overall and for the negative words. As for gender-specific effects, based on the hypothesis of stronger and more intense emotional reactivity in women, women were expected to give more extreme valence ratings, as well as higher mean arousal ratings than men, especially for the negative words.

Study II. This study aimed at examining the possible role of arousal in generating the age-related positivity effect in immediate free recall and recognition memory of intentionally encoded emotion-laden words. An intentional encoding paradigm was chosen for Studies II-IV to be able to examine neurocognition of successful explicit emotional memory encoding in healthy aging. At the time of starting data collection in 2009, little was known about the impact of using intentional vs. incidental encoding paradigms to study age-related effects of emotion on memory. It was only in 2014 that Reed and colleagues published their meta-analysis demonstrating that the emergence of the positivity bias in older adults was confined to studies using experimental paradigms of an unconstrained nature. However, the effect size was small, and these paradigms included other experimental designs than incidental encoding. Furthermore, Kensinger (2008) had demonstrated a positivity bias in older age regardless of encoding manner. The incentive to Study II came from the unexpected finding of a within-group positivity bias for the hit rate in Studies III and IV. Because the effects of valence and arousal were confounded in Studies III and IV, and because Kensinger (2008) had shown that the positivity effect emerged specifically for low-arousing words regardless of encoding intentionality, we were curious to find out whether our unexpected finding could reflect an interaction between arousal and valence-specific preferences in memory for words. Here a group of young adults was included, and the effects of both valence and arousal were studied on immediate free recall and on recognition memory accuracy as measured by hit rate, false alarm rate, and *d′*, as well as on response bias. The novel aspects of Study II included creating three levels of arousal (low, medium, high) for each of the word valence categories (positive, negative, neutral) for a more detailed analysis of valence effects at different levels of arousal. Based on previous findings in support of the CCM/SST account, an age-related positivity effect was expected to surface specifically for low-arousing words in both free recall and recognition memory. Also, a liberal response bias for emotion-laden words was expected to emerge in recognition memory based on previous work demonstrating more liberal response bias for emotion-laden than neutral stimuli (Charles et al., 2003; Comblain et al., 2004; Spaniol et al., 2008), and even age differences in response bias for a specific stimulus type (Spaniol et al., 2008; Thapar & Rouder, 2009). Furthermore, Comblain et al. (2004) showed unique overall effects of valence and arousal on memory accuracy and response bias.

Study III. The aim of this study was to examine the associations between regional GM volume and immediate free recall and recognition memory performance of intentionally encoded positive, negative, and emotionally neutral words, respectively, in a group of middle-aged and older healthy adults. In this study, both ROI analyses for amygdalar and hippocampal volumes as well as whole brain voxel-based morphometry (VBM) were performed. Previous studies on amygdalar volumetric associations have reported null findings in healthy aged samples, but these samples have included 20 participants at the most (Landré et al., 2013; Schultz et al., 2009). The sample in Study III encompassed 46 individuals representing a wider age range, enabling more variance in the measures and thus statistical power to detect subtle associations. Based on previous work (Kumfor et al., 2013; Mistridis et al., 2014), we expected to find associations between regional GM volume in the OFC and the ventromedial and ventrolateral PFC and memory for negative words, when controlling for performance on positive and neutral words. As for behavioral measures, based on earlier work (Reed et al., 2014) no positivity bias in the memory tasks was expected, as an intentional memory encoding paradigm was used.

Study IV. This study aimed to examine structural brain connectivity patterns in relation to recognition memory of intentionally encoded words of varying valence (neutral, positive, negative) in healthy middle-aged and older adults. This was accomplished by investigating associations between memory performance and WM microstructural properties as measured by FA and tract-based spatial statistics (TBSS). Previous work has favored as such limited ROI approaches, whereas here a whole brain approach without *a priori* assumptions was chosen. Based on earlier structural and functional neuroimaging studies (Addis et al., 2010; Charlton et al., 2013; Ford et al., 2014; Kensinger & Schacter, 2008; Lockhart et al., 2012; St Jacques et al., 2009; Yau et al., 2009), one could tentatively expect to find positive associations between memory for emotion-laden words and FA of corticosubcortical tracts subserving emotional memory. As in Study III, it was predicted that no positivity bias would be seen, as the present experimental paradigm called for intentional encoding (Reed et al., 2014).

2. Method

A summary of the demographic characteristics of the participants, methods, and main research questions is shown in Table 3. The study protocols for all four studies were approved by local ethics committees. All participants gave written informed consent for participation prior to entering the study in keeping with the Declaration of Helsinki and its later amendments. Special provision was made for the minors entering Study I. The local ethics committee waived the need for parental consent given that there were no privacy issues involved (all participants remained anonymous) and that participation in the study was deemed to carry only a minimal risk.

Table 3

Summary of the Participant Characteristics, Methods, and Research Questions in the Studies

Study	Research questions	Method	Participants	*N*	F/M	Age in years *M* (*SD*, [range])	Education in years *M* (*SD*, [range])
I	Valence and arousal evaluations of words	Web survey	Lifespan	996	754/242	32.91 (14.50, [16-77])	Various levels
II	Effects of valence and arousal on memory	Experimental memory tasks	Young adults	30	22/8	26.37 (3.99, [21-35])	14.07 (1.84 [12-17])
			Middle-aged and older adults	46	29/17	62.54 (8.15, [50-79])	13.55 (2.79 [6-17])
III	Regional gray matter correlates of memory	MRI, Voxel-based morphometry (VBM)	Middle-aged and older adults	46	29/17	62.54 (8.15, [50-79])	13.55 (2.79 [6-17])
IV	White matter microstructural correlates of memory	MRI/Diffusion tensor imaging (DTI), Tract-based spatial statistics (TBSS)	Middle-aged and older adults	44	28/16	62.59 (8.28, [50-79])	13.53 (2.85 [6-17])

2.1. Participants

2.1.1. Study I

This study employed a community sample of 996 respondents that were all native Finnish speakers, brought up in a monolingual home. The sample consisted of 75.7% women and 24.3% men, ranging in age from 16 to 77 years, M = 32.91, SD = 14.50. The sample was obtained through e-mail invitations. In addition, 157 respondents had been excluded for not fulfilling the only inclusion criterion of having Finnish as the native language, for having missing values in the demographic questionnaire part of the survey or in the ratings, or for having produced ratings that were mostly outliers.

2.1.2. Studies II-IV

A total of 87 community dwellers representing two age groups volunteered for the studies. Both age groups were convenience samples. The older adults were recruited first, via a regional newspaper. The young adult group was recruited via multiple other channels, and was stratified against the older adult group regarding gender and educational level. All 87 participants were monolingual native Finnish speakers with self-reported normal hearing, normal-to-corrected vision (eye glasses were permitted), and normal color vision. All 87 volunteers had been checked for fulfilment of the inclusion criteria via a telephone interview conducted prior to taking part in the study. Exclusion criteria included earlier or current neurological illness, a history of traumatic brain injury involving concussion, loss of consciousness, and/or post-traumatic cognitive dysfunction, current psychiatric diagnosis, current use of psychotropic medication, a history of psychoactive substance abuse, or having a close relative suffering from schizophrenia.

A neuropsychological assessment was conducted to ensure fulfilment of an additional inclusion criterion of normal cognitive functioning, defined as performance equal to or less than one standard deviation below the age-appropriate norms within a cognitive domain on a battery of standardized neuropsychological tests. A minor decline on an individual subtest was permitted as a sign of intra-individual variability, provided that performance within that cognitive domain as a whole fulfilled the criterion (Brooks, Holdnack, & Iverson, 2011). The neuropsychological test battery included Wechsler Adult Intelligence Scale-III subtests Similarities, Block Design, Digit Span, and Digit Symbol (Wechsler, 1996), Object Memory Test (naming, immediate and delayed free recall; Portin, Saarijärvi, Joukamaa, & Salokangas, 1995), Wechsler Memory Scale-Revised subtests Logical Memory I and II, and Verbal Paired Associates I and II (Wechsler, 1987), Boston Naming Test (Laine, Koivuselkä-Sallinen, Hänninen, & Niemi, 1987), Controlled Oral Word Association Test (letter fluency, category fluency; Benton & Hamsher, 1989), Trail Making Test (Poutiainen, Kalska, Laasonen, Närhi, & Räsänen, 2010), Stroop Color and Word Test (Dodrill, 1978), copy of Rey-Osterrieth Complex Figure Test (Osterrieth, 1944), Clock Drawing Test (from the Consortium to Establish a Registry for Alzheimer's Disease, CERAD; Morris et al., 1989), and drawing of three-dimensional figures (Lezak, 1995). Two young adults were excluded for failure to fulfil this criterion. For the older adults, normal cognitive functioning was further defined as a Clinical Dementia Rating memory box score of 0 (Morris, 1993), and a Mini-Mental State Examination score of at least 25 (Folstein, Folstein, & McHugh, 1975). Nine older adults were excluded for not meeting the inclusion criterion of normal cognitive functioning.

The final sample consisted of a group of 30 young adults in Study II (21-35 years, M = 26.37, SD = 3.99; 22 women; years of education: M = 14.07, SD = 1.84) and a group of 46 older adults in Studies II-IV (50-79 years, M = 62.54, SD = 8.15; 29 women; years of education: M = 13.55, SD = 2.79). The age groups were matched on gender and educational attainment. In study IV, two additional older adults were excluded due to technical issues during scanning, leaving 44 participants (50-79 years, M = 62.59, SD = 8.28; 28 women; years of education: M = 13.53, SD = 2.85).[3] All participants but one older adult were self-reported right-handers, as determined by a cut-off score of at least 87 on a

[3] Erratum: The original article for Study IV contains an erroneous standard deviation for age (+/- 1.25 years old) in the Participants section on p. 1346. Here it has been corrected to SD = 8.28.

modified version of the Edinburgh Handedness Inventory (Cohen, 2008).

For none of the older adults did next-of-kin report cognitive impairment in everyday life. All older adults were free from significant structural brain changes as determined by MRI visual rating score data. Eighteen (39.1%) participants exhibited no focal WM lesions (Wahlund et al., 2001). Twenty-four (52.1%) had focal lesions. Beginning confluence of lesions was seen in four (8.7%) participants. One participant exhibited general atrophy (Victoroff, Mack, Grafton, Schreiber, & Chui, 1994), one participant showed age-related left hippocampal atrophy, and two had age-related right hippocampal atrophy (score 1) (Scheltens et al., 1992). Frontal atrophy with a score of 1 (Jokinen et al., 2009) was found in four (8.7%) participants, whereas one participant had a score of 2 (Jokinen et al., 2009).

Monetary compensation was not provided, but all participants received written clinical feedback based on their individual neuropsychological performance by an experienced clinical psychologist (Carina Saarela) and on the MRI scan by a neuroradiologist (Riitta Parkkola).

2.2. Materials and procedure

2.2.1. Word evaluations (Study I)

The data for the word evaluation study were gathered by means of web surveys. The final 420 Finnish nouns were selected for the ratings from among 847 nouns based on the following criteria. All were nouns in nominative singular, which is the morphologically simple dictionary form in Finnish. As the aim was to create a database representative of the entire bivariate affective space for the purpose of the memory experiment, the nouns were chosen to represent positive, negative, and neutral valence categories, using ANEW (Bradley & Lang, 1999) as a guideline. ANEW contains 156 (37.1%) of the chosen words. All included nouns had low lexical ambiguity (homonymy) in the Turun Sanomat newspaper corpus (Laine & Virtanen, 1999) to ensure clear interpretation of meaning. The selected nouns were also checked for their surface frequency and their word length in letters. The selected 420 nouns had low to medium frequency, with a word length limited to a range of 5 to 9 letters. These choices were determined by the intent to use the nouns in memory research. Very short or long words were excluded, so as not to overly facilitate memory processing (Tehan & Tolan, 2007).

The web-based survey program provided by the Computing Centre at Åbo Akademi University at the time of data collection (Spring 2008) did not enable random selection of the words for evaluation or a randomized presentation order separately for each rater. Therefore, eight web surveys were created. The 420 Finnish nouns were pseudorandomized into four different word lists of 105 words each, all of which consisted of an equal number of nouns assumed to be rated as negative, neutral, and positive. The four word lists were matched on word length in letters, surface frequency, and lexical ambiguity rate. Each list was finally duplicated and rerandomized to minimize any order or habituation effects.

The first nine items in each web survey were questions concerning demographic data, physical health status, and psychiatric health status, followed by the rating of current level of arousal and feeling of pleasure, and overall level of arousal and feeling of pleasure during the past four weeks on a Likert-type scale ranging from 1 to 7. The remaining 105 items were the nouns to be rated.

A pilot study was conducted to specify appropriate survey length, clarity of the questions and instructions, and suitability of the initial 9-point Likert-scales based on the 9-point SAM scales (Bradley & Lang, 1994). The duration of approximately 15 minutes was deemed appropriate, and the valence and arousal scales were reduced to 7-point scales, because the pilot respondents did not give any extreme ratings.

The surveys were posted on the website of the Department of Psychology at Åbo Akademi University. An e-mail invitation with a link to one of the surveys was sent to various e-mail lists, and posted on two Finnish internet discussion forums for elderly adults to maximize demographic representativeness of the sample. The mailing lists were randomly distributed between the eight surveys with the limitation that a demographically representative sample of raters would be evaluating each of the four word lists. The surveys were open for approximately one month after having sent the invitations. A voluntary lottery of two gift vouchers (value: 100€ and 50€) to a national bookstore chain was used as an incentive. The contact information for the lottery was collected separately from the word evaluations to ensure privacy. When the data had been collected, the eight web surveys were merged to correspond to the initial four word lists. The supplementary material containing the database can be accessed at http://users.abo.fi/casoderh/wordrating/. The description of the material is found in Söderholm et al. (2013) (Study I).

2.2.2. Neurocognitive correlates of memory for emotion-laden words (Studies II-IV)

All volunteers took part in a neuropsychological assessment at the Department of Psychology at Åbo Akademi University and an electroencephalogram (EEG) experiment at the former Centre for Cognitive Neuroscience at the University of Turku. In addition, the older adult group had a MRI scan at the Department of Radiology, Turku University Hospital. Furthermore, prior to the neuropsychological assessment, all participants filled in several questionnaires, for example, to assess personality, and next-of-kin of the older adults completed questionnaires as to the everyday and psychological functioning of each participant. After the EEG experiment, the participants were asked to complete valence, arousal, and imageability ratings of the 150 target words. The neuropsychological assessment lasted approximately 3.5 hours including a short break, and it further included experimental memory tasks not reported in this thesis. The behavioral data (memory performance) for Studies II-IV were gathered by an immediate free recall task and a recognition memory task used in the EEG experiment that was conducted within a week of the neuropsychological assessment. EEG was recorded during task performance and during two resting state registrations. The EEG results will be reported elsewhere. The EEG session lasted altogether about 3 hours, including preparations. MRI data was collected within 21 weeks of the EEG experiment (mean interval = 13.4 weeks, *SD* = 5.8 weeks). MRI imaging lasted 30 minutes.

2.2.2.1. Immediate free recall and recognition memory tasks (Studies II-IV)

The participant was seated in a comfortable armchair about 1.2 m from a 19-inch TV screen. The word stimuli were displayed in white capital letters, Arial 40-point font, centrally aligned on a black background using Presentation version 14.9 software (Neurobehavioral Systems, Inc.). In the *immediate free recall* task, the instruction was to silently read and memorize a total of 150 Finnish nouns that were presented in fifteen 10-word lists varying in emotional valence, that is, five word lists of each word valence group, and to freely verbally recall the previous word list while a prompt was displayed on the screen.

The *immediate free recall* task started with a short practice run to familiarize the participant with the experimental procedure, followed by a study run. The study run encompassed 15 trials with ten words each that were presented only once. To avoid order effects, a 3 by 3 pseudorandomization format was used for the presentation order of the words within each study run list and the presentation order of the lists. No more than two word lists of the same emotional valence were presented in succession. The nine presentation orders were alternated on a participant-by-participant basis. A study run trial is depicted in Figure 2. The words were shown for 2 s followed by a 3-second interval. After each study run list, the participant had 60 s for verbal free recall of the previous word list. The researcher documented the word recall order and possible errors.

Figure 2. A study run trial of a 10-word list in the immediate free recall task. ITI = inter-trial interval. REF = reference. ISI = inter-stimulus interval.

Two filler tasks were administered after the immediate free recall task to prevent rehearsal of the stimuli. First, the participant was asked to count backwards aloud starting from 150, which was interrupted after 30 s. Second, the participant completed a five-minute 0-back task with consonants, which was also designed to familiarize the participant with the response pad.

After the 0-back task, about ten minutes after the immediate free recall task had been completed, memory for the target words in the immediate free recall task was examined using an old-new *recognition* task that included making yes-no confidence judgments. Using a response pad with the key assignment counterbalanced across participants, the participant was asked to identify the 150 target words from among 300 randomly presented words, half of which were new distractor stimuli.

A *recognition memory* study run trial is depicted in Figure 3. The participant was to make an old-new discrimination using a response pad, as a word was shown on the screen. After each old-new discrimination, the prompt for the yes-no confidence judgment was displayed on the screen. The participant was asked to respond as fast and precisely as possible. The recognition task also entailed a practice run and a study run. The study run included 300 trials. A word was shown up to 2 s, and then a black screen was displayed for 2.1 s, followed by the confidence judgment for a maximum time of 1.5 s.

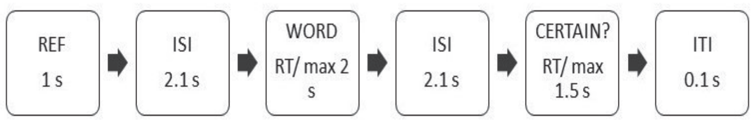

Figure 3. A study run trial in the recognition memory task. REF = reference. ISI = inter-stimulus interval. RT = reaction time. ITI = inter-trial interval.

Three hundred Finnish nouns in nominative singular were chosen from the word pool in Study I. For the purpose of the EEG experiment and Study II, the word valence groups were created as follows: negatively valenced words (mean valence < 3.00 on a Likert scale ranging from 1 to 7); emotionally neutral words (mean valence = 3.60-4.30); positively valenced words (mean valence > 5.00). The 150 targets and 150 distractors were matched on all emotional and psycholinguistic variables: valence, arousal, word length, surface frequency, lemma frequency, bigram frequency, initial trigram frequency, and final trigram frequency. Moreover, the distractors were chosen such that words that were closely semantically related to the target words were preferred. However, within targets and distractors, the mean valence ratings of the word valence categories expectedly differed significantly (positive > neutral > negative, all p-values < 0.001). The aim to control for the effect of the level of arousal elicited by these words on memory performance in the EEG experiment was not fully successful, because the positive and neutral target words were matched for arousal, but the negative words were on average significantly more arousing than both positive and neutral words. As for the distractor words, the neutral distractors were on average more arousing than the positive distractors, whereas the negative distractors were again significantly more arousing than both other valence categories. As this arousal-related confound stemmed from the original pool of 420 words (Study I), it could not be corrected. Matching within both targets and distractors on psycholinguistic features for the word valence categories was achieved for all variables.

For the purpose of Study II, the nouns were further grouped by their mean arousal score (low-arousing < 3.6; medium-arousing 3.6-4.3; and high-arousing > 4.3). Thus, there were nine stimulus categories with three levels of arousal for each of the three valence categories. When categorized by the nine valence-arousal combinations, targets and distractors were matched on arousal and the psycholinguistic variables, but not on mean valence (targets: high-arousing negative < low-arousing and medium-arousing negative, $p \leq .002$; distractors: low-arousing neutral > medium-arousing neutral, $p = .019$).

2.2.2.2. MR imaging (Studies III-IV)

In the present thesis, MRI data was acquired using a 3T scanner (Verio, Siemens Medical Imaging, Erlangen, Germany) equipped with a routine 12-channel head coil. MRI scanning was performed using the parallel acquisition technique (GRAPPA) in all sequences. Axial T2-weighted images had Repetition Time of 5210 ms, Echo Time of 96 ms, Field-Of-View of 220 mm x 165 mm, 4 mm slice thickness, and a 30% gap between images. Sagittal FLAIR sequence had Repetition Time of 5000 ms, Inversion Time of 1800 ms, Echo Time of 395 ms, Field-Of-View of 250 mm x 250 mm, voxel size 1 mm x 1 mm x 1mm, and 160 slices in total with go gap between slices. Sagittal 3DT1 sequence had Repetition Time of 2300 ms, Inversion Time of 900 ms, Echo Time of 3 ms, Field-Of-View of 256 mm x 240 mm, and Flip Angle of 9 degrees. For the DTI study (Study III), axial DTI employed Repetition Time of 9100 ms, Echo Time of 95 ms, Field-Of-View of 256 mm x 256 mm, matrix of 128 x 128, and resolution of 2 mm x 2 mm x 2 mm. The number of directions was 30.

In Study III, the volumetric segmentation of the *a priori* selected ROIs, left and right amygdalae and hippocampi, was undertaken with the Freesurfer image analysis suite (http://surfer.nmr.mgh.harvard.edu). In short, this processing encompassed motion correction and averaging (Reuter, Rosas, & Fischl, 2010), removal of non-brain tissue using a hybrid watershed/surface deformation procedure (Ségonne et al., 2004), automated Talairach transformation, and segmentation of the subcortical WM and deep GM volumetric structures (Fischl et al., 2002; Fischl et al., 2004). The automatic labelling technique confines the analysis to regions specific to the hippocampus, excluding cortical areas, and identifies the amygdalae using the hippocampi as anatomical landmarks (Fischl et al., 2002). Whole brain VBM analysis was performed using the VBM8 toolbox (Christian Gaser, University of Jena, Jena, Germany; http://dbm.neuro.uni-jena.de/vbm/) implemented in Statistical Parametric Mapping software (SPM8, Wellcome Department of Cognitive Neurology, London, UK) running in Matlab 2011a (Mathworks Inc., Natick, MA) (Ashburner, 2007; Ashburner & Friston, 2000, 2005; Cuadra, Cammoun, Butz, Cuisenaire, & Thiran, 2005). In short, the processing included high-dimensional DARTEL normalization to Montreal Neurological Institute (MNI) space, image intensity non-uniformity correction, and segmentation to GM, WM, cerebrospinal fluid, and three non-brain partitions. The GM images were modulated using Jacobian determinants derived from the normalization procedure and smoothed using an 8 mm Full-width-at-half-maximum (FWHM) isotropic Gaussian kernel. Total GM, WM, cerebrospinal fluid, and total intracranial volumes were calculated from the native space images.

In Study IV, whole brain voxel-wise statistical analysis of the DTI data was carried out using TBSS (Smith et al., 2006), a part of FSL, version 5.0.6 (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/) (Smith et al., 2004). TBSS projects all subjects' FA data onto a mean FA tract skeleton, before applying voxel-wise cross-subject statistics. Raw diffusion data was first corrected for eddy currents and patient head movement by affine registration to non-diffusion weighted image. FA, mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD) images were constructed by fitting a tensor model to the diffusion gradient data using the FMRIB Diffusion Toolbox (FDT). The acquired diffusion images were then cleared from all non-brain tissue by using the Brain Extraction Tool (BET; Smith, 2002). All subjects' data were then aligned into MNI 152 1mm standard space using the nonlinear FMRIB Linear Image Registration Tool (FNIRT; Andersson, Jenkinson, & Smith, 2007a, 2007b), which employs a b-spline representation of the registration warp field (Rueckert et al., 1999). Next, a mean FA image was calculated and thinned to create a mean FA skeleton, which represents the centers of all neural tracts common to the participant group. A threshold for FA values for the creation of the skeleton was chosen at ≥ 0.25 in order to not only exclude peripheral areas from the skeleton, which can include excess amount of cross-subject variability and result in biased results, but also to preserve as much of the relevant WM areas as possible. Each subject's aligned data was then projected onto this skeleton for each DTI parameter, and the resulting skeletonized data was fed into voxel-wise cross-subject statistics.

2.2.3. Statistical analyses

2.2.3.1. Study I

The shape of the distribution of mean valence and arousal ratings of the whole sample was examined by plotting the ratings in a scatter plot, by using a model fit analysis, and by conducting pairwise correlation analyses separately for negative, positive, and emotionally neutral nouns. In the model fit analysis, mean valence rating was the independent variable, and mean arousal rating the dependent variable.

Two 4 x 2 x 3 factorial analyses of variance (ANOVA) were conducted with age group (adolescents vs. young adults vs. middle-aged adults vs. older adults), gender (women vs. men), and word valence (positive vs. negative vs. neutral words) as between-subjects factors, and the mean ratings of valence and arousal for each word as dependent variables, respectively. Follow-up analyses were performed when needed. Only results significant at the $p < .01$-level are reported for the follow-up analyses to correct for multiple comparisons and to minimize the risk for Type I error. We opted to refrain from the Bonferroni adjustment, because it may be too conservative, thus increasing the risk for Type II error (Perneger, 1998).

To examine the level of convergence of our ratings with those in other databases, Pearson correlation analyses between valence ratings and arousal ratings in the present database and in three other databases were conducted.

2.2.3.2. Study II

Five 2 x 3 x 3 factorial ANOVAs with the between-subjects factor age group (young vs. older adults), and the within-subjects factors valence (positive vs. negative vs. neutral), and arousal (low vs. medium vs. high) were performed on the dependent variables. The dependent variables were proportional scores for correctly recalled words at immediate free recall (see Study II description above), hit rates and false alarm rates (number of hits/false alarms divided by the maximum scores in each valence-arousal category), d', and a response bias measure, the bias index B_r. B_r was calculated using the equation false alarm rate/[1 - [hit rate – false alarm rate)] (Snodgrass & Corwin, 1988). Values below .50 indicate conservative or "new" bias, whereas values above .50 indicate liberal or "old" bias. Because values of 0 or 1 were observed for hit rates and false alarm rates, loglinear scores were calculated for d' and B_r (Stanislaw & Todorov, 1999). As Levene's test suggested heterogeneity of variances, the hit rate variable was reflected and logarithmically transformed because of negative skewness, and the false alarm rate variable was logarithmically transformed due to positive skewness. The follow-up analyses encompassed one-way

ANOVAs with scores grouped by valence category as dependent variables conducted at every level of the arousal factor and Gabriel´s post hoc tests (chosen because of unequal sample sizes and heterogeneity of variances). Only results significant at $p < .01$ are reported for the omnibus analyses to check for experiment-wise error rate, and for the follow-up analyses to adjust for multiple comparisons and to diminish the risk for Type I error. The statistical analyses were performed with SPSS version 24 (SPSS Inc. IBM Company, 2016).

2.2.3.3. Study III

The behavioral analyses were carried out using two repeated measures ANOVAs with valence as the within-subject factor (three levels) separately for immediate free recall and recognition memory performance. The dependent variables consisted of the proportional scores at immediate free recall and for the hit rate for pooled responses regardless of confidence judgment at recognition described in Section 2.2.3.2. Because preliminary analyses indicated a significant correlation between age and immediate free recall scores, age was included as a covariate in that ANOVA. The equality of variances at different levels of the repeated factor was checked using Mauchly's test of sphericity. *Post hoc*-analyses comparing different levels of the within-subjects factor were performed using paired samples *t*-tests with Bonferroni-correction ($\alpha_{corrected}$ = 0.05 / 3 (valence)] = 0.017). All statistical analyses of the behavioral data were performed with SPSS version 21 (SPSS Inc. IBM Company, 2012).

The relationship between memory performance and amygdalar and hippocampal volumes, respectively, were analyzed using hierarchical linear regression analyses using SPSS version 21 (SPSS Inc. IBM Company, 2012). In the first step, whole brain total GM, gender, and age were used as covariates to control for the variability in head size and overall cortical volume, and the potential confounding effects of gender and age, respectively. The second step introduced the scores for opposite valence and neutral words (when valenced words acted as dependent variables), or for positive and negative words (when neutral words acted as the dependent variable) as covariates to control for "baseline" episodic memory performance. The final third step included left and right amygdalar or hippocampal volumes (separately to avoid multicollinearity) as predictors for memory performance.

Finally, age, gender, total intracranial volume, and memory performance with the two other valence categories were used as nuisance variables (covariates of no interest) in all the voxel-wise multiple regression analyses. An absolute voxel value threshold of 0.1 was used to confine the analyses to the brain GM regions. Statistical significance was set at family-wise error (FWE) corrected *p* less than 0.05 at cluster level. Anatomical regions in clusters were defined using the Automated Anatomical Labeling (AAL) toolbox (http://ww.gin.cnrs.fr/AAL) (Tzourio-Mazoyer et al., 2002). The peak coordinates are presented in MNI standard space. Visualization was carried out with the Mango software (version 4.0.1; Lancaster, Martinez, http://rii.uthscsa.edu/mango/).

2.2.3.4. Study IV

The same behavioral analyses were performed on the hit rate at recognition as in Study III, only with two participants less in the sample. For the DTI data, statistical correlation analysis was performed applying a robust method for significant cluster diagnostics called Threshold-Free Cluster Enhancement (TFCE; Smith & Nichols, 2009) to eliminate the alignment problem present in the regular type of whole brain voxel-wise methods, as well as partial volume effects. Also, an initial cluster size input is not required when using the TFCE approach. Correlation inference was obtained via a non-parametric permutation-based statistics program, Randomise (Winkler, Ridgway, Webster, Smith, & Nichols, 2014). A nonparametric one-tailed *t*-test with GLM design was used for statistics (Nichols & Holmes, 2002), with the significance level set at 0.05 (corrected for multiple comparisons) and using 5000 permutations. Multiple comparisons correction for permutation testing was carried out by building up the null distribution of the maximum (across voxels) TFCE score, and then testing the acquired TFCE image against the null distribution. Age was used as a nuisance variable. To examine the unique association between FA and memory performance in a valence category, partial correlations were conducted by controlling for performance in the two other valence categories. Partial correlation coefficients were calculated from the *t*-statistics output of TBSS. TBSS results were associated to corresponding tract structures using the ICBM-DTI-81 WM labels atlas (included in FSL).

3. Results

3.1. Study I

3.1.1. The distribution of mean valence and arousal ratings in affective space

Figure 4 shows the distribution of the mean valence and arousal ratings in the bivariate affective space. The model fit analysis replicated the quadratic relationship denoting the curvilinear shape of the distribution, such that nouns rated as either positively or negatively valenced were also rated as more arousing than emotionally neutral nouns. As expected, the association between valence and arousal ratings was weaker for the positive than the negative nouns, even to the extent that pairwise correlation analyses conducted separately for the word valence categories revealed that the positive nouns exhibited a near-zero correlation. When classifying the nouns into arousal categories, the classification patterns were significantly different for each word valence group. The results indicated a lack of low-arousing negative nouns in this database, and a pronounced prevalence of low-arousing positive nouns compared to the neutral nouns. Also, more negative nouns were classified as high-arousing, compared to the other word valence categories.

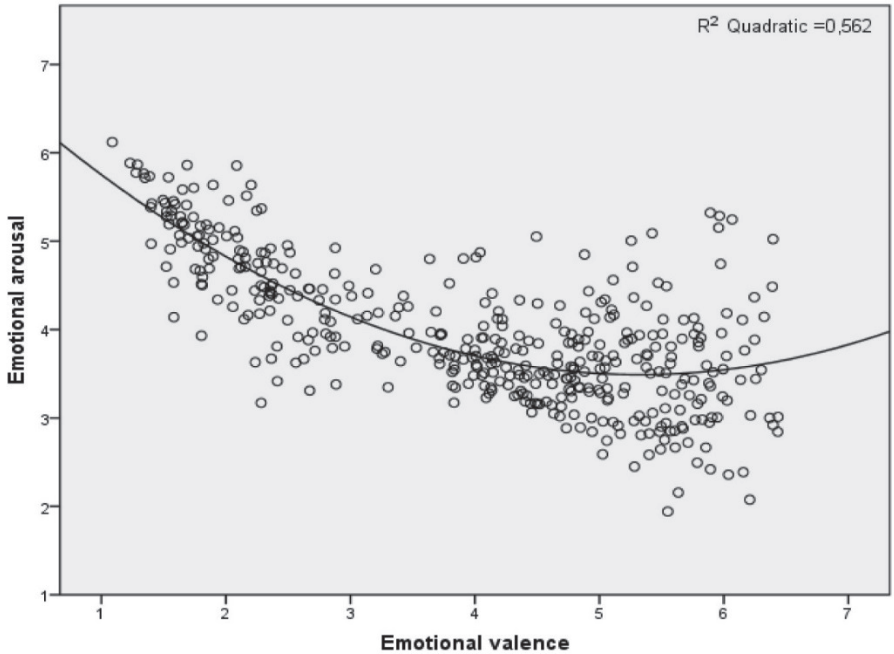

Figure 4. The relationship between valence and arousal ratings for each word averaged across all participants.

3.1.2. Age and gender differences in valence and arousal ratings

The factorial ANOVA with mean *valence* ratings as the dependent variable showed a main effect of all the independent variables, qualified by three significant two-way interactions: an Age x Word valence interaction, a Gender x Word valence interaction, an Age x Gender interaction; and a significant three-way Age x Gender x Word valence interaction. Contrary to expectations, follow-up analyses of the three-way Age x Gender x Word valence interaction revealed that females gave more extreme negative ratings for the negative nouns than the males only in the adolescent group. However, women did give significantly more extreme positive ratings than men for the positive nouns irrespective of age. Women compared to men rated the neutral nouns as more positive in the young adult and older adult groups.

The factorial ANOVA with mean *arousal* ratings as the dependent variable showed a main effect of all the independent variables, qualified by three significant two-way interactions: an Age x Word valence interaction, a Gender x Word valence interaction, and an Age x Gender interaction. Follow-up analyses of the Age x Word valence interaction revealed lower arousal ratings for the negative nouns for the adolescents compared to the other age groups, and for middle-aged adults compared to young adults, and older adults. Therefore, older adults did exhibit comparatively enhanced arousal ratings for negative nouns. Lower arousal ratings were also seen for the neutral nouns for adolescents compared to young adults and older adults, and for middle-aged adults compared to young adults and older adults. The gender effects largely fulfilled the expectations. Follow-up analyses of the Gender x Word valence and the Age x Gender interactions showed that women gave significantly higher arousal ratings for negative and neutral nouns than men, as well as higher mean arousal ratings overall regardless of age group.

The decidedly strongest effects in both factorial ANOVAs were the main effects of word valence. This indicates that the demographic characteristics of the raters had a relatively small impact on the valence and arousal ratings for these nouns.

3.1.3. Correlations with valence and arousal ratings in other databases

Our database had 54 words in common with the database in Finnish established by Eilola and Havelka (2010). Valence ratings correlated very strongly, but surprisingly, the correlation between arousal ratings failed to reach statistical significance. Pairwise correlation analyses between arousal ratings separately for negative, neutral, and positive nouns showed that only the correlation for the negative nouns reached statistical significance.

One hundred fifty-six words of those in our study could be found both in ANEW (Bradley & Lang, 1999) and in Redondo et al. (2007), which contains all the ANEW words translated to Spanish. The correlations between valence ratings from the two databases were again strong, whereas the arousal ratings correlated more weakly but still significantly. The correlations between arousal ratings conducted separately for negative, neutral, and positive nouns were all statistically significant, and showed acceptable strength.

3.2. Study II

The main finding in all the factorial ANOVAs was a lack of significant interaction effects with age, indicating that there were no age-specific valence or arousal effects on memory performance. In other words, no evidence for a positivity effect in memory was found in this study. However, all memory accuracy measures, that is, immediate free recall, hit rate, false alarm rate, and *d´*, but not response bias, B_r, showed a main effect of age. Table 4 demonstrates that the young adults showed higher overall free recall, hit rate, and *d´* scores, but lower false alarm rate than the older adults.

Table 4

Means and Standard Deviations of the Scores for the Memory Measures in the Two Age Groups

	Young adults (n = 30)			Older adults (n = 46)			
Variable	*M*	*SD*	95% CI	*M*	*SD*	95% CI	*p*
Immediate free recall	.67	.19	[.65, .70]	.49	.18	[.47, .50]	< .001
Hit rate[a]	.79	.17	[.77, .81]	.71	.20	[.69, .73]	< .001
False alarm rate[a]	.18	.18	[.16, .20]	.25	.21	[.23, .27]	< .001
d´[b]	1.71	0.70	[1.63, 1.79]	1.25	0.67	[1.19, 1.32]	<. 001
B_r [c]	.46	.23	[.43, .49]	.47	.23	[.45, .49]	.497

Note. CI = confidence interval.
[a] Untransformed scores are reported. [b] As some hit and false alarm rates were 0 or 1, *d´* was calculated using loglinear scores (Stanislaw & Todorov, 1999). [c] Response bias scores were calculated with the loglinear scores for *d´* using the bias index, B_r, of the two-high-threshold model, as defined in Equation (8) by Snodgrass and Corwin (1988): B_r = false alarm rate/[1 – (hit rate – false alarm rate)].

The results of the post hoc tests for the factorial ANOVAs are displayed in Table 5. The factorial ANOVA with *immediate free recall* *performance* as the dependent variable yielded significant main effects of age, and arousal, and a significant two-way Valence x Arousal interaction, which demonstrated better free recall for valenced words specifically at high arousal.

For *reflected and logarithmically transformed hit rate*, main effects were shown for all three factors. Follow-up tests for the main effect of valence demonstrated a higher mean hit rate for positive words than for neutral words. The main effect of arousal reflected better performance for low-arousing and high-arousing words than for medium-arousing words.

Regarding *logarithmically transformed false alarm rate*, main effects of age and valence were found, qualified by a significant two-way Valence x Arousal interaction. Follow-up tests yielded a significantly higher mean false alarm rate for low-arousing emotion-laden words than for neutral words, a higher mean false alarm rate for positive medium-arousing words than for either negative or neutral medium-arousing words, and a higher mean false alarm rate for negative high-arousing words than for neutral high-arousing words.

For d', the factorial ANOVA yielded main effects for all factors, age, valence, and arousal, modulated by a two-way Valence x Arousal interaction. Follow-up tests showed that memory accuracy as measured by d' was higher for both positive and neutral words compared to negative words at low arousal only.

Finally, regarding B_r, a main effect of valence, qualified by a marginally significant two-way Valence x Arousal interaction was shown. Follow-up analyses demonstrated significantly higher B_r for emotion-laden low-arousing and high-arousing words compared to neutral words, suggesting a liberal response bias for emotion-laden words. Regarding medium-arousing words, significantly higher B_r was seen only for positive words compared to neutral words.

Group differences in mood were examined to ascertain that possible findings in the main analyses were unrelated to current mood, the so-called mood congruency effect (Clore et al., 2001). The older adults exhibited a significantly higher score only on the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996) than the young adults, but none of the bivariate Pearson correlations between the BDI-II score and the memory measures indicated a mood congruency effect in either age group.

Table 5

ANOVA Comparisons of the Effect of Valence on Memory Accuracy and Response Bias at Different Levels of Arousal

		Valence			
		Positive	Negative	Neutral	
Score	Arousal	*M (SD)* [95% CI]	*M (SD)* [95% CI]	*M (SD)* [95% CI]	Post hoc
Immediate free recall	Low	.61 (.15) [.58, .64]	.60 (.22) [.54, .65]	.61 (.17) [.58, .65]	ns
	Medium	.52 (.20) [.48, .57]	.51 (.19) [.47, .56]	.56 (.18) [.52, .60]	ns
	High	.61 (.20) [.56, .65]	.57 (.14) [.54, .60]	.45 (.32) [.37, .52]	pos = neg > neu
Hit rate[a, b]	Low	.80 (.13) [.77, .83]	.76 (.22) [.71, .81]	.70 (.16) [.66, .73]	-
	Medium	.72 (.18) [.68, .76]	.72 (.15) [.68, .75]	.67 (.16) [.63, .71]	-
	High	.80 (.16) [.77, .84]	.77 (.13) [.74, .81]	.75 (.31) [.68, .82]	-
False alarm rate[b]	Low	.26 (.15) [.23, .30]	.25 (.30) [.18, .32]	.12 (.12) [.10, .15]	pos = neg > neu
	Medium	.33 (.21) [.28, .37]	.21 (.16) [.17, .25]	.20 (.16) [.16, .24]	pos > neg = neu
	High	.22 (.24) [.16, .27]	.27 (.16) [.24, .31]	.13 (.17) [.09, .17]	neg > neu
d´ [c]	Low	1.60 (0.59) [1.46, 1.73]	1.15 (0.85) [0.95, 1.34]	1.79 (0.69) [1.63, 1.95]	pos = neu > neg
	Medium	1.10 (0.72) [0.93, 1.26]	1.36 (0.60) [1.22, 1.49]	1.37 (0.71) [1.20, 1.53]	ns
	High	1.55 (0.69) [1.39, 1.70]	1.47 (0.55) [1.34, 1.59]	1.52 (0.75) [1.35, 1.69]	ns
B_r [d]	Low	.55 (.22) [.50, .60]	.55 (.20) [.50, .59]	.30 (.18) [.26, .35]	pos = neg > neu
	Medium	.53 (.23) [.48, .58]	.45 (.21) [.40, .50]	.37 (.21) [.33, .42]	pos > neu
	High	.53 (.23) [.48, .59]	.53 (.22) [.48, .58]	.35 (.20) [.31, .40]	pos = neg > neu

[a] Non-significant valence x arousal interaction effect. [b] Untransformed scores are reported. [c] As some hit and false alarm rates were 0 or 1, *d´* was calculated using loglinear scores (Stanislaw & Todorov, 1999).[d] Response bias scores were calculated with the loglinear scores for *d´* using the bias index, B_r, of the two-high-threshold model, as defined in Equation (8) by Snodgrass and Corwin (1988): B_r = false alarm rate/[1 – (hit rate – false alarm rate)].

3.3. Study III

The two repeated measures ANOVAs used for the behavioral analyses to examine the effect of emotional content on immediate free recall and recognition memory performance in the sample of 50-79-year-old healthy adults yielded a significant main effect of valence at recognition. Contrary to expectations, follow-up paired samples *t*-tests demonstrated a significantly higher hit rate for positive words than for either negative or neutral words, as well as for negative words compared to that for neutral words.

The hierarchical regression analyses with the ROI volumes as predictors for memory performance separately for each valence category, accounting for whole brain total GM, age, gender, and memory performance in the two other valence categories, yielded a single significant positive association between right amygdalar volume and the hit rate for negative words. However, more detailed analyses showed that the finding was probably a result of statistical suppression. The attempt to pinpoint the suppressor(s) did not succeed, which is quite common in multiple regression analyses according to Tabachnick and Fidell (2007). These results suggest that left and right amygdalar volumes did not predict immediate free recall performance in any valence category or hit rates at recognition for positive and neutral words. Furthermore, there were no statistically significant associations between hippocampal volumes and memory performance on any measure.

As for *the whole brain VBM results*, the anatomical labeling of the clusters is presented in Table 6. At *immediate free recall*, higher recall of negative words was associated with less regional GM volume in two clusters in unexpected locations in the frontal lobe: one in the dorsomedial PFC comprising the premotor and primary motor cortices in the superior frontal and precentral gyri, and one in the left dorsolateral PFC (Figure 5a; Table 6). Also, immediate free recall performance for positive words was positively correlated with local GM volume in the cerebellum, specifically in a cluster centered mainly in bilateral Crus II in the mediolateral hemispheres of the posterior lobe (Figure 5b; Table 6).

Table 6

Anatomical Region, %Cluster, Cluster Size in Voxels, Peak Coordinates (MNI), and Significance Levels of All Significant Associations between Local GM Volume and Memory for Emotion-Laden Words

Anatomical region	Laterality	%Cluster[a]	k[b]	Peak (x, y, z)[c]			Sig.[d]
				x	y	z	
Immediate recall of negative words							
Supplementary motor area	Right	20.4	15015	6	3	57	< 0.001
Superior frontal gyrus	Right	13.7					
Supplementary motor area	Left	9.3					
Paracentral lobule	Right	9.0					
Medial frontal gyrus	Right	8.1					
Precentral gyrus	Left	7.1					
Medial frontal gyrus	Left	5.8					
Paracentral lobule	Left	4.9					
Middle frontal gyrus	Right	4.6					
Middle frontal gyrus	Left	66.4	2681	-27	50	25	0.037
Superior frontal gyrus	Left	28.5					
Immediate recall of positive words							
Cerebellum Crus II	Right	27.7	3627	4	-75	-47	0.008
Cerebellum Crus II	Left	24.7					
Cerebellum lobule VIII	Right	6.1					
Cerebellum lobule IX	Left	5.8					
Cerebellum lobule IX	Right	4.4					
Recognition of positive words							
Calcarine sulcus	Right	25.0	8109	21	-49	-5	< 0.001
Lingual gyrus	Right	22.3					
Cuneus	Right	11.9					
Superior occipital gyrus	Right	9.6					
Cuneus	Left	8.6					
Calcarine sulcus	Left	5.2					
Fusiform gyrus	Right	4.4					

[a] Percentage of total cluster size. [b] Cluster size in voxels. [c] Peak coordinates in MNI space. [d] Family-wise error (FWE) corrected p.

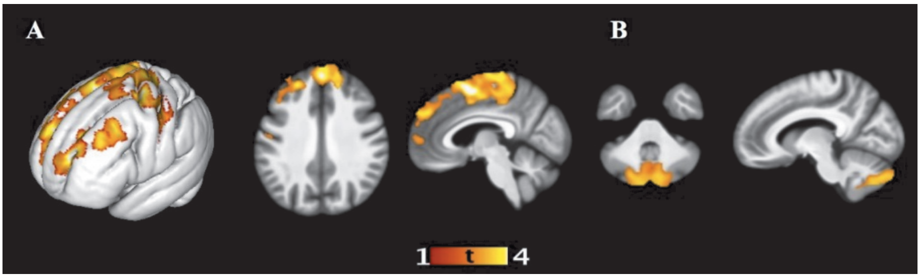

Figure 5. Immediate free recall and local GM volume. Association between local GM volume and (a) immediate free recall of negative words (negative association, height threshold T = 2.43, peak at 6 3 57 mm, cluster size 15015 voxels, $p_{FWE} < 0.001$, and peak at -27 50 25, cluster size 2681 voxels, $p_{FWE} = 0.037$), and (b) immediate free recall of positive words (positive association, height threshold T = 2.43, peak at 4 -75 -47 mm, cluster size 3627 voxels, $p_{FWE} = 0.008$). The statistically significant clusters are overlaid on the average normalized T1-weighted image of the studied sample.

At *recognition*, higher hit rates of positive words were significantly associated with less local GM volume in the occipital lobe mainly in the cuneus, extending into the lingula and primary visual cortex (Figure 6; Table 6).

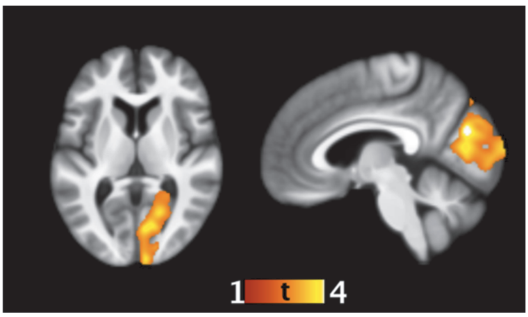

Figure 6. Association between recognition memory of positive words and local GM volume. The statistically significant cluster (negative association, height threshold T = 2.43, peak at 21 -49 -5 mm, cluster size 8109 voxels, $p_{FWE} < 0.001$) is overlaid on the average normalized T1-weighted image of the studied sample.

3.4. Study IV

For the behavioral results, see section 3.3 Study III above. Further results are presented in the supplementary material accompanying the original article. As for the TBSS results, only associations for clusters of at least 10 voxels are reported to avoid Type I error. Only associations between recognition memory for positive words, controlling for age and memory for negative and neutral words, and FA reached statistical significance. A higher hit rate was related to lower FA of several projection, association, and commissural tracts in the left hemisphere (Figure 7; Table 7).

Table 7

White Matter Tract Label, Cluster Size in Voxels, Peak Coordinates (MNI), Partial Correlation Coefficient, t-Value, and Significance Levels of All Significant Negative Associations between Fractional Anisotropy (FA) and Recognition Memory for Positive Words

White matter tract[a]	*k*[b]	Peak (*x*, *y*, *z*)[c]			*r*	*t*	Sig.[d]
		x	*y*	*z*			
Projection tract							
Anterior corona radiata	151	-26	17	21	0.294	1.92	0.031
Posterior corona radiata	272	-28	-25	32	0.302	1.98	0.035
Superior corona radiata	581	-27	6	28	0.281	1.83	0.035
Anterior limb of internal capsule	60	-21	14	13	0.254	1.64	0.044
Posterior limb of internal capsule	52	-27	-20	15	0.296	1.94	0.049
Retrolenticular part of internal capsule	95	-27	-28	14	0.304	1.99	0.049
Sagittal stratum[e]	22	-37	-50	-8	0.338	2.25	0.047
Posterior thalamic radiation[f]	348	-32	-50	12	0.300	1.93	0.036
Association tract							
Superior longitudinal fasciculus	725	-38	-13	28	0.323	2.13	0.032
External capsule	15	-28	-21	15	0.300	1.95	0.049
Commissural tract							
Splenium of the corpus callosum	113	-16	-45	21	0.273	1.77	0.036

Note. All significant associations were localized to the left hemisphere. Only clusters of at least 10 voxels are reported.
[a] Anatomical locations based on ICBM-DTI_81 white matter labels, included in FSL. [b] Cluster size in voxels. Voxel size 1 mm^3. [c] Peak coordinates in MNI space of the most significant voxel inside the anatomical structure. [d] Mean significance level of the anatomical structure. [e] Includes parts of the association tracts inferior longitudinal fasciculus and inferior fronto-occipital fasciculus. [f] Includes optic radiation.

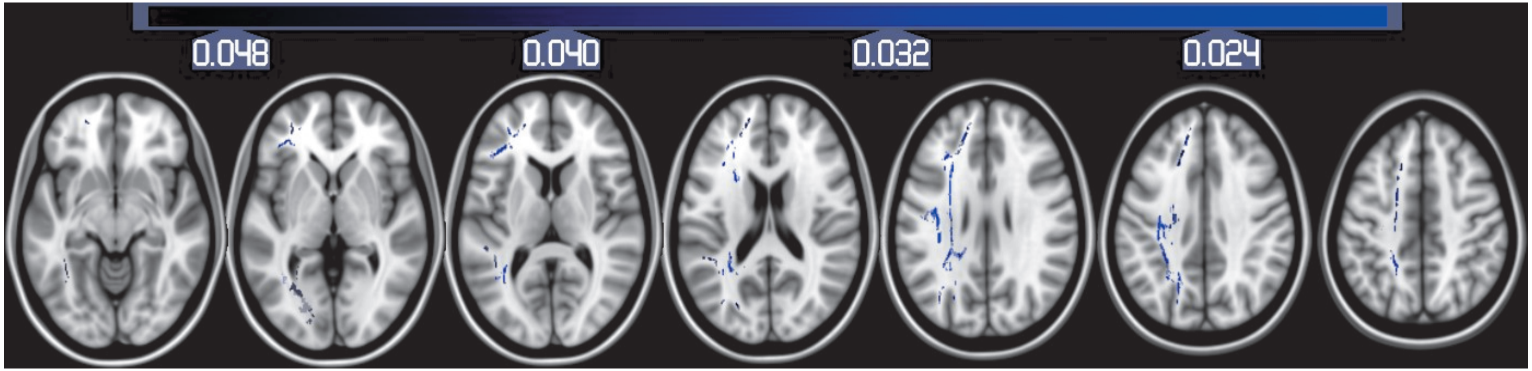

Figure 7. TBSS analysis results of the partial correlations between FA and recognition memory for positive words. The skeleton areas with statistically significant ($p < 0.05$) negative correlations are presented with shades of blue, overlaid on top of the MNI-ICBM152 non-linear T1 model. p-value scale drawn from 0.05 to 0.02. Neurological convention (left is left).

4. Discussion of the individual studies

4.1. Description of the word stimulus database

Study I was conducted to create and describe the characteristics of a normative word pool containing general as well as age- and gender-specific valence and arousal ratings for 420 Finnish nouns. Additionally, the usefulness of the database in experimental studies was enhanced by including corpus-based frequency values, as these objective psycholinguistic measures are known to affect word processing (Adelman & Estes, 2013; Cortese et al., 2010; Diana & Reder, 2006; Tehan & Tolan, 2007). The word ratings in this database were analyzed by examining the distribution of the ratings in the affective space, possible age and gender differences in mean valence and arousal ratings for all nouns and for nouns categorized by their mean valence ratings, as well as the relationships between evaluations in the present study and those in previous databases (Bradley & Lang, 1999; Eilola & Havelka, 2010; Redondo et al., 2007).

As expected, the distribution of these nouns in the bivariate affective space resembled the typical U-shape (Bradley & Lang, 1999, 2017; Eilola & Havelka, 2010; Fairfield et al., 2017; Ferré et al., 2012; Hinojosa et al., 2016; Kanske & Kotz, 2010; Keil & Freund, 2009; Monnier & Syssau, 2014; Montefinese et al., 2014; Redondo et al., 2007; Soares et al., 2012; Warriner et al., 2013), with the exception of the positive nouns for which the arousal ratings were more evenly dispersed over the arousal scale. More specific analyses revealed an unexpected null correlation between valence and arousal ratings for the positive nouns. This finding was corroborated in a later study by Fairfield et al. (2017) using only older adult raters. Therefore, the expectation that the linear relationship between valence and arousal ratings would be stronger for the negative than the positive nouns due to the inclusion of older adult raters in the sample was confirmed (Fairfield et al., 2017; Keil & Freund, 2009).

Several studies with older adult raters have indicated a less pronounced quadratic relationship between valence and arousal in older age (Fairfield et al., 2017; Gilet et al., 2012; Grühn & Smith, 2008). When taking a closer look at the findings, Fairfield et al. (2017) noted that older adults, compared to young adults in a previous study by the same research group (Montefinese et al., 2014), tended to give more extreme high-arousal ratings for the negative words (see also Keil & Freund, 2009), and more pronounced low-arousal ratings for the positive words (Fairfield et al., 2017). Study I yielded similar age-specific findings for the negative nouns. Various explanations have been offered for these age-related patterns. High-arousal stimuli being evaluated as more negative by older adults may be related to the diminished capacity in older age to regulate physiological arousal (e.g., Duffy, 1957) and to inhibit processing of high arousal (e.g., Wurm et al., 2004). This would constitute evidence for the DIT (Labouvie-Vief, 2003; Labouvie-Vief et al., 2010), ABM (Cacioppo et al., 2011), and SAVI (Charles, 2010; Charles & Hong, 2016) theories on age-related changes in cognition-emotion interactions. Alternatively, this finding could be a consequence of an interaction between the fact that negative stimuli commonly are considered more high-arousing than positive stimuli (Hamann, 2003; Rozin & Royzman, 2001) and that the immediate emotional response to events that elicit negative affect has a higher-intensity quality in older adults (Carstensen et al., 2000).

Attributing the null correlation between valence and arousal for positive nouns solely to the inclusion of older adult raters appears to be a less likely explanation. First, the older adult group in Study I was comparatively small. Also, older adults do not consistently exhibit higher arousal ratings for negative words (Grühn & Smith, 2008; Grunwald et al., 1999), and differences in valence-arousal correlation strength between ratings for positive vs. negative words do not necessarily emerge despite including older adults (Warriner et al., 2013). Second, studies using only young adult raters have reported similar results (Ferré et al., 2012; Hinojosa et al., 2016, Montefinese et al., 2014; Soares et al., 2012). Third, in this database, and in line with previous work (Grühn & Smith, 2008; Soares et al., 2012), there were more high-arousing nouns among the negative ones than among the neutral and the positive ones. This has been suggested to indicate greater general reactivity to negatively valenced stimuli (see Keil & Freund, 2009). Janschewitz (2008) posited that the enhanced arousal ratings of negative words might constitute a natural property of the affective lexicon.

It is important to consider the characteristics of normative databases containing ratings of affective stimulus properties because of their potential behavioral effects. The attention-grabbing effect of negative word types, which ultimately leads to enhanced memory for these stimuli (e.g., Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001), may be a consequence of their relative rarity in natural language that renders them marked (Warriner & Kuperman, 2015). However, in the present database, all words represented low- to medium surface frequency. It should also be pointed out that the stronger relationship between negative valence and high arousal is not unique to word stimuli. The relationship between the constructs of valence and arousal remains debated. Some studies suggest that the asymmetrical relationship between valence and arousal in the affective space indicates that these dimensions are orthogonal, bipolar, and independent (Fairfield et al., 2017; Osgood, Suci, & Tannenbaum, 1957). Still, many studies report a clear (inverted) U-shaped curve (e.g., Bradley & Lang, 1999, 2017; Warriner et al., 2013), suggesting that these constructs are interrelated. All in all, the fact that the relationship between valence and arousal is different for negative and positive words in the present database creates a confound, and hence, a problem when compiling stimulus lists based on these items. This issue is discussed further in the General Discussion (Chapter 5).

Correlations with ratings in other databases were examined to probe the consistency of the ratings. A perplexing finding in this respect was the non-significant correlation between the arousal ratings in our study and those for Finnish nouns in the study by Eilola and Havelka (2010). Again, the weak correlation arose from a very low correlation between arousal ratings for the positive nouns. In fact, a closer analysis of the arousal ratings for single positive words showed near-opposite ratings for some of these words. This finding is not easily explained in light of the significant positive correlations with the arousal ratings for the positive words in ANEW (Bradley & Lang, 1999) and Redondo et al. (2007), indicating consistency for these ratings. Possible explanations may lie in a lower number of common words with our database and in the different conceptualizations of the arousal scale. In line with previous work (Eilola & Havelka, 2010; Fairfield et al., 2017; Montefinese et al., 2014; Redondo et al., 2007; Soares et al., 2012; Warriner et al., 2013), all the correlations between arousal ratings in the different languages were weaker compared to the correlations between the valence ratings. This is thought to indicate culture-specific differences in emotional reactivity to words.

The expectation that we would find age and gender differences in valence and arousal ratings for these nouns was confirmed. However, regarding the valence ratings, the main effects of all these factors were qualified by a three-way interaction. As predicted, and in line with previous research suggesting a stronger reactivity to emotion-laden stimuli in women (Bellezza et al., 1986; Monnier & Syssau, 2014; Montefinese et al., 2014; Soares et al., 2012), we found that women gave more extreme mean valence ratings at both ends of the scale. However, the more extreme valence ratings were given at the negative end of the scale only in the adolescent group. Furthermore, more positive ratings were also given for the neutral nouns by young as well as older adult women.

The age and gender effects on arousal ratings partially supported our predictions, as interaction effects were observed here as well. In partial support of the findings by Keil and Freund (2009) and Fairfield et al. (2017) as well as of our expectations, but in contrast to the findings by Grühn and Smith (2008), higher arousal ratings for the negative nouns were given by older adults than adolescents and middle-aged adults. Note, however, that the adolescents and middle-aged adults perceived the negative nouns as less arousing than all the other age groups. In partial agreement with previous work by Grunwald et al. (1999), older adults gave equally high mean arousal ratings as young adults for neutral nouns, but higher than adolescents and middle-aged adults. Contrary to the findings by Grühn and Smith (2008) and Fairfield et al. (2017), positive nouns exhibited no age differences in arousal ratings.

In partial support for the contention of stronger and more intense reactivity to stimuli in women, in agreement with our expectations, and partially in line with the study by Grunwald et al. (1999), women gave higher mean arousal ratings for the negative and the neutral, but not the positive nouns, than men in every age group. The present study was the first to report interaction effects between age and gender for valence and arousal ratings of written words.

The effect sizes for the statistically significant age and gender differences in valence and arousal ratings were quite small. This has been observed in previous studies as well (e.g., Bellezza et al., 1986; Grühn & Smith, 2008), although in some studies, age or gender differences for arousal ratings have shown medium effects sizes, compared to very small effects for valence ratings (Fairfield et al., 2017; Montefinese et al., 2014). The effect sizes for the valence factor were decidedly larger. Consequently, it would seem that the language- and culture-specificity of valence and arousal ratings of words might be a more important feature than the demographic characteristics of the emoter.

The use of a web survey in Study I carries both benefits and drawbacks. Using a web survey, a large public sample of raters can be collected in a time- and cost-efficient way. Although care was taken to ensure that the requirements presented by Dillman, Tortora, and Bowker (1998) were met, the problem of coverage, that is, non-response due to lack of computer skills or access to computers (Dillman & Bowker, 2001), was nevertheless present in this study, particularly regarding the older adults. The age range was 16 to 77 years, but the mean age was only 33 years. This limitation arose even though organizations for elderly adults and heterogeneous demographic groups were approached to reach a representative sample. The results of Study I are not generalizable to the Finnish population at large, because age and gender distributions of our sample are not representative of those at the time of data collection. Calculating response rates or view rates, participation rates, and completion rates was not possible with the available survey tool (Eysenbach, 2004). However, the data were thoroughly screened for multiple responses and missing values, and seemingly unreliable cases were removed from the statistical analyses.

4.2. No age differences in valence-arousal interactions on memory

Study II was prompted by the unexpected behavioral results in Studies III and IV, encompassing a positivity bias at recognition. A positivity bias was not expected in either task in Study III, because an intentional encoding paradigm was used (Reed et al., 2014). However, it should be noted that the effect size in the meta-analysis by Reed et al. (2014) was rather small. A previous study by Kensinger (2008) demonstrated that the positivity effect with a negativity bias in young adults and a positivity bias in older adults was seen for low-arousing words only, irrespective of encoding paradigm and retrieval task type. The positive words used in Studies III and IV were on average relatively low-arousing. Therefore, it was hypothesized that the unexpected positivity bias at recognition may have resulted from an interplay between valence and arousal rather than being a "pure" effect of valence. Consequently, Study II set out to investigate the effects of both affective dimensions on memory in young and older adults. A novel aspect of Study II entailed the creation of three levels of arousal for each word valence category, in contrast to previous work that had opted for only two categories (low, high), and consistently only for valenced stimuli (Kensinger, 2008; Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). The main finding of Study II was the disconfirmation of the first hypothesis, which was based on Kensinger's study (2008) that could be seen as evidence for the CCM/SST account, entailing the emergence of the age-related positivity effect for low-arousing words in both free recall and recognition memory. In fact, no valence- and/or arousal-related interaction effects with age were found for memory accuracy or response bias measures. The second hypothesis of a liberal response bias for emotion-laden words in recognition memory was corroborated. Moreover, an interaction between valence and arousal irrespective of age was observed in better free recall for high-arousing valenced words, and in multifaceted valence-arousal interactions for false alarm rate and accuracy (d') measures in recognition memory. The inclusion of a third (medium) level of arousal and examining interactions with arousal also for words of neutral valence produced distinct effects for some recognition memory measures. In line with earlier research (Fernandes et al., 2008; Spaniol et al., 2008), a mood congruency effect in memory was not observed for the older adults despite their relatively more depressive mood. In line with the previous observations of a general age-related memory decline also for emotion-laden stimuli despite maintained EEM in older adulthood (Kensinger & Gutchess, 2017), young adults outperformed older adults on all memory accuracy measures. This may indicate general age-related resource limitations (Kensinger & Gutchess, 2017).

As Kensinger (2008) also used word stimuli and an intentional encoding paradigm, the prediction of the emergence of the positivity effect at low arousal rested on her findings despite failures to replicate them in later studies (Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Wang & Yang, 2017; Waring & Kensinger, 2009). None of the theoretical frameworks mentioned in Section 1.2.4., CCM/SST or DIT, would predict age-invariant effects only, and both frameworks would predict preferential memory particularly for positive words at low arousal in older adults. Furthermore, age-specific interaction effects with valence and/or arousal on memory have been demonstrated in previous studies (Kensinger, 2008; Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Waring & Kensinger, 2009). However, CCM/SST would predict age-invariant effects on memory specifically for high-arousing words, which is in line with the same contention by Matlin and Stang (1978, cited in Mickley & Kensinger, 2009). This prediction was supported in immediate free recall. Wang and Yang (2017) also demonstrated age-invariant effects of valence and arousal on memory, but age differences did arise when modulating factors apart from arousal, such as contextual features, were accounted for. This suggests that also stimulus-related factors other than arousal may contribute to the age-related positivity effect in memory.

Methodological aspects, such as using pictorial stimuli and a third level of arousal to group the stimuli in all three word valence categories, can explain the discrepancies between the present results and most of the previous studies (Mickley & Kensinger, 2009; Tomaszczyk & Fernandes, 2013; Waring & Kensinger, 2009). However, the reasons for the differences between our results and those of Kensinger (2008) are more difficult to fathom because of the many similarities in experimental design. Still, there were methodological differences, such as a differently conceptualized arousal scale, a larger age difference between the groups (cf. Reed et al., 2014), a longer word viewing time combined with a simultaneous lexical decision task during encoding, viewing all target words at once in an emotion-heterogeneous list, and a different response format in Kensinger (2008). Moreover, Study II is different from all previous studies, because the behavioral data were gathered while simultaneously recording EEG. It is thus possible that the participants may have experienced heightened physiological arousal due to anxiety. Because of the elevated sensitivity to physiological arousal in older adults (e.g., Duffy, 1957), this may have affected memory performance and interaction effects between age and stimulus-related arousal. Neither subjective nor physiological arousal were directly measured, but no age differences were found in mean positive affect (PA) or negative affect (NA) as measured by an unpublished adaptation (Saarela, Rönnholm, & Svedström-Koskinen, 2011) of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1985), or elevated NA suggestive of distress at the beginning of the experimental session. PA and NA contain items measuring activation levels and anxiety. Also, EEM at high arousal was seen in both age groups in immediate free recall.

Some studies have proposed that arousal does not contribute to the age-related valence-specific preferences in memory, because using it as a covariate did not significantly change the age x valence interactions (e.g., Charles et al., 2003), or because experiments using stimuli varying in the extent of the arousal-related confound yielded similar results (Kensinger, O'Brien, Swanberg, Garoff-Eaton, & Schacter, 2007). Although there were no interactions between age and emotion in the present study, the role of arousal should still be considered in future work in light of the distinct influence of valence and arousal on all recognition memory accuracy measures (hit rate, false alarm rate, d'), which is in line with previous studies (Charles et al., 2003; Fernandes et al., 2008; Mickley & Kensinger, 2009). Furthermore, when comparing the findings in the present between-groups design to those in the within-groups design in Study III (and IV), it becomes clear that it is pivotal to specifically account for the effect of arousal instead of using it as a covariate, which is questionable from a statistical point of view (Miller & Chapman, 2001). In Study III, no effect of emotion on immediate free recall was found, even though it could have been expected based on a meta-analysis that showed a larger EEM for free recall than recognition (Murphy & Isaacowitz, 2008). When the level of arousal was considered in the present study, an overall EEM in free recall was seen specifically for high-arousing words. The results for the hit rate at recognition were also affected by separating valence and arousal effects in the present study.

It should be noted that response bias effects cannot explain the valence-arousal interaction in recognition memory, because response bias was predominantly liberal for valenced words at all levels of arousal irrespective of age. Previous work has yielded mixed effects in this regard (Adelman & Estes, 2013; Charles et al., 2003; Comblain et al., 2004; Spaniol et al., 2008; Thapar & Rouder, 2009). However, it is possible that d' was contaminated by response bias regarding neutral high-arousing words, as the standard deviations of hit rate and false alarm rate were dissimilar for this word type (Stanislaw & Todorov, 1999). Therefore, the hypothesis of a liberal response bias for emotion-laden words could be confirmed, but more consistently in relation to the valence than the arousal dimension. It has been proposed that the liberal response bias for emotion-laden stimuli (Charles et al., 2003; Comblain et al., 2004) may indicate that these stimuli are more fluently processed at the perceptual level, evoking a stronger sense of familiarity (Thapar & Rouder, 2009).

In this study, there was a confound in the interaction between valence and arousal, as the negative high-arousing words had been rated on average as more negative than their low- and medium-arousing counterparts. In addition to the above-mentioned possible limitations to the generalizability of these results, one should also note the variable amount of words in the nine valence-arousal categories (but see Söderholm et al., 2013 (Study I); Waring & Kensinger, 2009).

The results of this study show that the influence of emotion on memory performance can be understood as stemming from the interaction between several factors, including valence, arousal, retrieval process, and response bias, even though the effect sizes for emotion factors were generally small. Also, the lack of interaction effects with age may indicate that prioritized processing of emotion-laden information is preserved with age. In future studies, examining the effects of arousal on the age-related positivity effect in memory could benefit from the simultaneous study of the effects of possible age-related and other individual differences in subjective experience, physiological arousal, and basic memory proficiency (Leal et al., 2016).

4.3. Regional gray matter (GM) correlates of memory for emotion-laden words in aging

In Study III, regional GM volumetric correlates of memory for emotion-laden and emotionally neutral words on immediate free recall and recognition memory tasks were examined. The main findings were nonsignificant correlations between hippocampal or amygdalar ROI volumes and immediate free recall or recognition memory performance for all valence categories, as well as novel results in the whole brain VBM analyses. Regarding the whole brain VBM results, first, immediate free recall of negative words was negatively associated with local GM volume in the frontal cortex, encompassing clusters in the dorsomedial and left dorsolateral PFC. Second, immediate free recall of positive words was positively correlated with larger regional GM volume in the mediolateral hemispheres of the posterior lobe of the cerebellum. Third, a negative association was found between recognition memory of positive words and regional GM volume in the occipital cortex, encompassing a large area in the cuneus, extending into the lingula, and thus comprising the primary visual cortex. There were no statistically significant associations for memory for emotionally neutral words or recognition memory of negative words. Behaviorally, there was no effect of emotional content on immediate free recall performance. However, the middle-aged and older adults demonstrated both EEM and a positivity bias in recognition memory, in that the mean hit rates of both positive and negative words exceeded that of neutral words, and positive words were better recognized than negative words. This finding was discussed in section 4.2 on Study II.

In line with previous work with middle-aged and older healthy adults (Guzmán-Vélez et al., 2016; Landré et al., 2013; Schultz et al., 2009), amygdalar volume did not significantly predict memory performance in any valence category, apart from the positive association with the hit rate of negative words, which probably originated from statistical suppression. When positive findings have been reported for amygdalar volumetric correlates of memory for emotion-laden stimuli, mixed samples of patients with neurodegenerative diseases and healthy controls have been used

(Kumfor et al., 2013, 2014; Mistridis et al., 2014), which tends to entail greater variance in measures, thus enhancing the statistical power to detect associations (Sollberger et al., 2009). Indeed, restricted variance in both memory performance and amygdalar volume was indicated in the scatterplots representing the statistically significant relationships between these measures in the supplementary material in Mistridis et al. (2014) when looking at the separate groups. Furthermore, evidence is inconsistent as to the existence of age-related changes in amygdalar GM volume (e.g., Fjell et al., 2013; Jernigan et al., 2001; Kalpouzos et al., 2009). It is also to be noted that the general assumption of a positive relationship between regional GM volume and better performance does not hold for the amygdalae. Larger amygdalar volume has been associated not only with better emotional memory performance (Kumfor et al., 2013, 2014; Mistridis et al., 2014), but also with a history of early adverse life experiences (Tottenham et al., 2010). Moreover, functional brain connectivity studies have shown increased functional density of an amygdala-based network with age (Tomasi & Volkow, 2012) and a stronger positivity effect in memory for older adults with stronger medial PFC-amygdala connectivity during rest (Sakaki, Nga, & Mather, 2013). This may indicate that the structural integrity of the amygdalae in healthy aging may be less consequential for emotional memory performance than their connectivity with other brain regions.

Earlier studies on hippocampal volumetric correlates of memory for emotion-laden stimuli in healthy adults have yielded mixed findings. In line with Landré et al. (2013) and Schultz et al. (2009), but in contrast to Guzmán-Vélez et al. (2016), no significant associations between hippocampal volume and emotional memory emerged in Study III. The mixed results in previous studies may be explained by methodological differences between studies, such as group composition, stimulus type, memory measures, and methods of analysis. A positive association between hippocampal volume and memory performance might have been expected in this sample. Hippocampal volume reduction has consistently been observed after age 60 in normal aging (e.g., Allen et al., 2005; Fjell et al., 2013), hinting at the possibility of sufficient variability in this measure for a structure-function correlation to emerge. Moreover, a meta-analysis using emotionally neutral stimuli in healthy participants over the lifespan found a weak positive relationship in older age (Van Petten, 2004). However, the main finding for the older age groups was higher variability in both hippocampal volume and memory performance. It is not unusual to report null findings on the association between hippocampal volume and memory performance in normal aging (Ellfolk et al., 2013). These null findings have been attributed to subtle or no functional effects of the small volumetric changes in the hippocampi accompanying healthy aging, since the changes may have non-pathological developmental origins (Gautam et al., 2011). By comparison, the positive associations observed in the face of neuropathology have been suggested to indicate that larger hippocampal volumes correspond to larger remaining portions of functional neural tissue, generating better performance, also denoted the 'bigger is better' hypothesis (Gautam et al., 2011).

In contrast to previous studies (Kumfor et al., 2013; Mistridis et al., 2014), the frontal lobe volumetric correlates for memory for negative words were not located in the OFC and ventromedial and ventrolateral PFC. Instead, there was a negative correlation between *immediate free recall of negative words* and local GM volume in the dorsomedial PFC and the left dorsolateral PFC. Again, the different localization may stem from previous studies having used mixed samples of patients with neurodegenerative conditions and healthy older adults. The negative correlation is proposed to reflect that these frontal areas are involved in the cognitive control of emotion (Adolphs, 2009; MacDonald et al., 2000; Ochsner & Gross, 2005; Ochsner et al., 2012) and in self-referential processing (Fossati, 2012; Herold et al., 2016; Schmitz & Johnson, 2007).

The PFC areas involved in cognitive control functions engage in directing attention towards relevant stimuli, and in interpreting the meaning of these stimuli, so as to regulate the activity to achieve congruency with the implicitly activated goal (Adolphs, 2009; Champod & Petrides, 2007; Corbetta et al., 2009; Fossati, 2012; Lindquist et al., 2012; Miller & Cohen, 2001; Ochsner & Gross, 2005; Ochsner et al., 2012). According to the CCM/SST account, the implicit goal of middle-aged and older adults comprises the promotion of a more positive emotional state (Carstensen et al., 1999; Mather, 2012; Mather & Carstensen, 2005; Ngo et al., 2016; Reed & Carstensen, 2012), which is achieved by diverting attention away from unpleasant information (Reed et al., 2014), such as high-arousing negative words, and by semantic elaboration or self-referential processing of low-arousing information (Kensinger, 2008). This requires cognitive control

(Reed et al., 2014), because high-arousing information is thought to be automatically processed (Kensinger, 2008), causing automatic capture of attention (Kensinger & Schacter, 2016). This is proposed to occur because facilitated or prioritized processing of arousing stimuli holds evolutionary benefits to the organism (Allen et al., 2008; Dolan, 2002; Hamann, 2001; Lang & Bradley, 2010). Therefore, provided that the structural integrity and functional efficiency of these frontal areas are positively correlated, this negative association between regional frontal GM volume and immediate free recall of negative, relatively high-arousing words could signify that reduced local GM volume in these areas may have brought an attenuation of the cognitive control necessary to represent and actively maintain the implicitly activated goals for them to guide behavior. Consequently, the regulatory processing required for achieving goal-congruent behavior was incapacitated, leading to arousal-driven automatic processing, which ultimately resulted in better memory for these stimuli by virtue of their attention-grabbing effect. This explanation rests on the assumption that amygdalar arousal-driven activation during processing of emotion-laden stimuli reflects automatic processing, but Pollock et al. (2012) have suggested that it might actually reflect engagement of top-down control processes.

Support for this explanation of the results can also be found in functional neuroimaging studies demonstrating a preference of older adults to direct more neurocognitive resources to the processing of positive information and to down-regulate emotional responses to negative information, particularly in frontal areas (e.g., Ebner, Johnson, & Fischer, 2012; Gunning-Dixon et al., 2003). A recent study also offered further evidence to that effect, demonstrating preferential engagement of dorsal vs. ventral PFC regions by older adults during retrieval of valenced images depending on subjective vividness of memory for these images (Ford & Kensinger, 2017). Younger adults recruited ventral PFC regions in a valence-unspecific manner, or showed the reversed pattern in dorsal PFC recruitment. As for the absence of a correlation with the ventromedial PFC, patients with lesions in these areas, but not in the basal forebrain, exhibited normal EEM despite atypical reactivity to emotion-laden stimuli (Bechara, Damasio, & Damasio, 2000), indicating that EEM is not primarily subserved by the ventromedial PFC. Furthermore, Gautam et al. (2011) demonstrated a negative association between volume and cortical thickness of the lateral PFC and performance on a verbal memory composite score consisting of immediate and delayed free recall of a word list in older age, suggesting that the negative structure-function relationship in the present study may apply to verbal episodic memory in general.

An explanation in line with the CCM/SST account rather than the DIT/ABM account is offered here for this finding, because the deficit-based DIT and ABM theories would hold that age differences in valence-specific preferences of emotion-laden stimuli are mainly driven by bottom-up automatic processes (Reed & Carstensen, 2012). As the present structure-function correlation was negative and localized to the frontal lobes, an explanation involving cognitive control processes was considered as more feasible. The CCM/SST account has been considered argumentative in light of the overlap between the PFC areas activated during emotion regulation (Adolphs, 2009; MacDonald et al., 2000; Ochsner & Gross, 2005; Ochsner et al., 2012) and the PFC areas that exhibit age-related degradation (Mather, 2016), as well as the documented age-related decline in cognitive control efficiency (Mather & Carstensen, 2005; Reed & Carstensen, 2012). However, older adults tend to prefer less cognitively taxing emotional regulation strategies that rely on brain areas with better maintained functional efficiency in older age (for a review, see Mather, 2016). Still, the explanation of the present results involves the disruption of PFC-driven cognitive control functions. Nonetheless, there is support for the CCM/SST account for the age differences in cognition-emotion interaction (Mather, 2012, 2016; Mather & Knight, 2005; Reed et al., 2014). Another possibility could be the "fronto-amygdalar age-related change in emotion" theory (FADE; St Jacques, Bessette-Symons, & Cabeza, 2009). It posits that the age-related reduction in amygdalar activation is part of an age-related change in a neural network subserving negative stimulus perception. However, as no correlations with amygdalar volume emerged, a network-based account for this finding may not be feasible.

Another unexpected result in Study III was that the regional GM volumetric correlate of *immediate free recall of positive words* was localized to a cerebellar cluster centered in bilateral Crus II of the mediolateral hemispheres of the posterior lobe. This brain region has not been implicated in the neural network underpinning EEM (Allen et al., 2008; Hamann, 2001; McGaugh, 2000), or in previous studies on regional GM correlates of memory for emotion-laden stimuli (Kumfor et al., 2013; Mistridis et al., 2014). However, some functional neuroimaging studies on memory for emotion-laden stimuli have indeed observed cerebellar activations during encoding and retrieval, but not discussed them (Dolcos et al., 2005; Kensinger et al., 2011). During the past decades, the role of the cerebellum has been shown to extend beyond subserving sensorimotor functions to taking part in distributed neural networks subserving higher cognitive functions and emotional processes (Bostan, Dum, & Strick, 2013; Buckner, Krienen, Castellanos, Diaz, &, Yeo, 2011; D'Angelo & Casali, 2013; Habas et al., 2009; Schmahmann, 1996; Schmahmann & Caplan, 2006; Schmahmann & Sherman, 1998; Stoodley & Schmahmann, 2009). The cerebellum is thought to serve a modulatory function via different neural pathways connecting it with cortical and subcortical cerebral brain areas (D'Angelo & Casali, 2013; Schmahmann, 1996). The connectivity pattern overlaps with clinical and neuroimaging findings on cerebellar functional topography (Bostan et al., 2013; Schmahmann, 1996; Schmahmann & Caplan, 2006; Stoodley & Schmahmann, 2009).

Lesion studies (Baillieux, De Smet, Paquier, De Deyn, & Mariën, 2008; Schmahmann & Sherman, 1998) and functional neuroimaging studies (Andreasen et al., 1999; Cabeza et al., 1997; Grönholm, Rinne, Vorobyev, & Laine, 2005) have shown that the cerebellum is involved in a variety of learning and memory tasks, including recognition memory of emotion-laden stimuli in young adults (Dolcos et al., 2005; Fossati et al., 2004). Previous functional or structural neuroimaging studies have not demonstrated cerebellar contributions to memory for emotion-laden words in middle-aged and older adults. The positive association between posterior cerebellar GM volume and immediate free recall of positive, relatively low-arousing words is a novel finding. Also here, the data would favor an explanation suggestive of a CCM/SST account. As previously stated, the positivity bias in memory for low-arousing stimuli that may surface in middle and older healthy adulthood has been hypothesized to be driven by constantly activated motivational goals to ensure emotional well-being via cognitive control processes (Reed et al., 2014). Provided that larger cerebellar volume indicates stronger functional efficiency, it may be that the positive association between local GM volume in the mediolateral hemispheres of the posterior cerebellum and immediate recall of positive, low-arousing stimuli reflects the conjoint effect of the involvement of these areas in cognitive control (Buckner et al., 2011; D'Angelo & Casali, 2013; Habas et al., 2009; Miquel et al., 2016; Picazio & Koch, 2015), inhibitory control on arousal (Posner et al., 2009), facilitation of reward system functioning (Heath, Franklin, Walker, & Keating, 1982; Turner et al., 2007), and self-relevant and self-referential processing (Herold et al., 2016; Schmitz & Johnson 2007) in middle-aged and older adults. Also, lobule IX may be a node in the default mode network, which seems to be involved in episodic memory and self-reflection (Buckner et al., 2011).

Finally, a higher hit rate at *recognition of positive words* was related to smaller local GM volume in the cuneus and lingula of the occipital lobe, specifically in an area corresponding to the primary visual or striate cortex (BA 17, V1). Both the localization and direction of the association were unexpected. Meta-analyses on functional neuroimaging studies have found that the occipital areas V2 to higher visual association cortices (BA 18 and beyond), not V1 (BA 17) (Lindquist et al., 2012; Phan, Wager, Taylor, & Liberzon, 2002), tend to show activation to emotion-laden stimuli. Also, a study on the relationship between EEM in story recall of narrated slides and GM intensity revealed a correlation located to BA 18 (Kumfor et al., 2014). In studies on the incidental encoding of emotion-laden stimuli, the activation of the primary visual cortex to stimuli has been unrelated to emotional content (Kensinger & Corkin, 2004; Tabert et al., 2001). However, it is not entirely clear whether the primary visual cortical activation is unspecific to emotion-laden stimuli, because some studies have reported enhanced occipital activation to memory for emotion-laden stimuli without specifying the precise location of the cluster (Dolcos et al., 2005; Hamann et al., 1999). In fact, emotional discrimination of faces has evoked stronger activation of the cuneus (BA 17) in young adults (Gunning-Dixon et al., 2003).

There are limitations to the interpretation of these results. The interpretation is based on theories on the mechanisms that drive cognition-emotion interaction in middle-aged and older adults, which could be seen as problematic as age was controlled for in the VBM analyses. Therefore, the results could be taken as age-invariant, which would rule out age-specific interpretations. However, the sample still represented middle-aged and older adults. It is known that results of studies on GM volumetric correlates of behavior reflect the age of the participants and the presence of brain pathology (Maillet & Rajah, 2013). This is assumed to indicate that the microstructural mechanisms underlying regional GM volume as measured by VBM are likely to differ for young adults, normally aged adults, and people with neuropathological conditions (Kanai & Rees, 2011; Maillet & Rajah, 2013). After all, it is not precisely known what microstructural features and which cellular events are reflected in local GM volume as measured by VBM (Kanai & Rees, 2011). Furthermore, when the effect of using age as a covariate was evaluated in a study, a negative correlation between PFC regional volume and cognitive measures in healthy older adults remained significant after controlling for age (Salat, Kaye, & Janowsky, 2002).

Another limitation concerns the use of automated software-based tracing of the amygdala, as previous studies have shown that the identification of the amygdala using even very sophisticated software is challenging compared to manual tracing (Entis, Doerga, Barrett, & Dickerson, 2012; Guzmán-Vélez et al., 2016). However, the algorithm for the detection of amygdalar volume of the automatic labelling technique used in this study is considered to be quite reliable and valid (Fischl et al., 2002).

4.4. White matter microstructural correlates of emotional recognition memory in aging

There were no previous studies on FA associations with recognition memory of positive, negative, and neutral words in healthy older adults using TBSS. We found left-lateralized FA associations only for recognition memory of positive words in bidirectional intrahemispheric and interhemispheric-posterior cortico-cortical and cortico-subcortical association and commissural tracts, as well as in cortico-subcortical projection tracts. No significant associations emerged for the other word valence categories. Quite unexpectedly, and contrary to earlier cross-sectional studies on FA associations with memory performance for emotionally neutral stimuli (Bender, Prindle, Brandmaier, & Raz, 2016; Bennett & Madden, 2014; Charlton et al., 2013; Yau et al., 2009), all associations were negative, that is, a higher hit rate for positive words was correlated with lower FA values. These results were mirrored in positive correlations for MD and RD, respectively, in almost all the same WM tracts (see Supplemental Digital Content 1-5 of the original article).

Because of the puzzling direction of the brain-behavior relationships, the *post hoc* explanations should be considered tentative, but as for the VBM findings, a CCM/SST account seems to offer a feasible explanation. According to the myelin hypothesis, lower FA together with higher RD may reflect myelin and/or axon loss (Jones et al., 2013), and is assumed to indicate slower neural conduction (Scholz et al., 2014). Therefore, when slower neural transmission is related to better memory, a compensatory mechanism may explain the findings. CCM/SST would posit that the positivity bias in memory in middle and older adulthood surfaces for low-arousing stimuli, because positive, low-arousing stimuli require controlled processing (Kensinger, 2008). It may thus be that the unexpected positivity bias in recognition memory arose here because the positive words were relatively low-arousing. At a neural level, this bias in older adults seems to be subserved by different functional brain activation (Ford et al., 2014; Kensinger & Schacter, 2008; St Jacques et al., 2009) and connectivity (Addis et al., 2010; Ford et al., 2014; St Jacques et al., 2009) patterns than in young adults, especially in areas that drive cognitive control functions, suggesting compensation. A multimodal imaging study on source memory indicated that older adults compensated for age-related deterioration of WM microstructure by functional overactivation of the connected brain areas (Daselaar et al., 2015). In Study IV, functional compensation is suggested by the correlations in many WM tracts linking areas related to memory, attention, and arousal (Addis et al., 2010; Catani & de Schotten, 2008; Ford & Kensinger, 2014; Ford et al., 2014; Kensinger & Schacter, 2008; Lockhart et al., 2012; Schmahmann & Pandya, 2006; St Jacques et al., 2009), as well as by the left-lateralized associations, as left-lateralized brain activation has been observed during encoding of positive stimuli (Kensinger & Schacter, 2008). Although the compensation account offered here rests on the assumption that lower FA is associated with slower neural transmission (Scholz et al., 2014), it is to be noted that Scholz et al. (2014)

still cautioned against equating increased axon calibre or thicker myelination with better behavioral performance. They proposed that increasing the speed and integrity of the complex spatio-temporally integrated nervous signals could have detrimental net effects on behavior. This could entail, for example, interference phenomena or increased likelihood for adopting a less effective behavioral strategy (Scholz et al., 2014). Putnam, Wig, Grafton, Kelley, and Gazzaniga (2008) suggested that improved trans-callosal connectivity indexed by FA and MD may lead to more effective inhibition of homologous areas in the non-dominant contralateral hemisphere, as associations with differences in functional activation and subsequent behavioral performance were also observed. At a neurobiological level, these results may reflect that the association is mediated by factors other than myelin. For example, lower FA is seen for larger axons that have faster neuronal conduction velocity (Scholz et al., 2014). Lower FA could also reflect differences in axon orientations in the voxel, such as a region with kissing or crossing fibers (Jeurissen, Leemans, Tournier, Jones, & Sijbers, 2013; Jones et al., 2013). Crossing fibers can be found in 60-90% of the WM voxels, but when using the kind of lower-quality DTI methods as in this study, the amount is probably lower (Jeurissen et al., 2013). In sum, these findings may reflect a complex interplay between the positivity bias in memory, structural integrity, and functional (compensatory) mechanisms in middle and older adulthood.

TBSS-derived anatomic region labelling may have limited correspondence to the actual WM tracts identified in probabilistic atlases, particularly in areas with fibers of multiple orientations (Bender et al., 2016). DTI tractography is more anatomically specific, and future studies preferring that method would be warranted. Also, small tracts of relevance to memory, such as the fornix, are difficult to identify using TBSS due to partial volume effects. More than half the sample displayed age-related WM changes. Even though image thresholding was used to separate normal-appearing and lesioned WM, a known relationship exists between macrostructural WM changes, such as lesions, and low FA tissue (Bennett & Madden, 2014). Using TBSS, potential areas of interest may be excluded from statistical analysis due to thresholding of the mean FA skeleton, if FA is too reduced in lesioned tissue. Also, there may be inter-individual variation in voxel-wise lesion location, causing the single-voxel-wide WM skeleton to pass through lesioned regions in different spatial locations for different subjects. However, TBSS reduces this effect by mapping the maximum local FA perpendicular to the skeleton to individual skeleton voxels, so that FA values on the skeleton reflect the greatest proximal WM structural integrity in lesioned regions rather than the effect of lesion on the integrity. On a related note, there is conflicting evidence on the contribution of microstructural and macrostructural WM changes to cognitive functioning in middle and older age (Bennett & Madden, 2014). In some studies with older samples, macrostructural changes, such as WM hyperintensities, have been better predictors of cognitive performance than FA (Bennett & Madden, 2014; Lockhart et al., 2012), while in other studies the opposite finding has been reported (Bennett & Madden, 2014). In normal aging, WM changes are less severe than in disconnection syndromes, which would entail less efficient network functioning instead of a loss of communication between regions (Charlton et al., 2013).

5. General discussion

The general aim of this thesis was to examine the neurocognition of memory for emotion-laden words in normal aging (Studies II-IV). To that end, a word evaluation study (Study I) was first conducted to create a normative database for the affective properties of these words. These norms were then used for stimulus selection for the three subsequent studies (Studies II-IV), which aimed at a) investigating the role of arousal in age differences concerning valence-specific preferences in memory; and b) studying the neuroanatomical underpinnings of memory for emotion-laden words in healthy middle-aged and older adults. The valence and arousal ratings in the database in Study I were also described. This is important, as affective stimulus properties may prompt behavioral effects. For example, the attention-grabbing and consequently memory-enhancing effect of negative word types (e.g., Baumeister et al., 2001; Rozin & Royzman, 2001) may derive from their relative rarity in natural language that renders them conspicuous (Warriner & Kuperman, 2015). However, in this database, all words had low- to medium surface frequency in written language, and behaviorally, no specific memory enhancement for negative high-arousing words was observed (Studies II-IV) despite the relative abundance of this word type in the database (Study I). Age and gender effects on the ratings should be known to enhance experimental control when using these stimuli with samples of variable age and gender compositions. In Studies II-IV, the same behavioral data, performance on an immediate free recall task and an old-new recognition memory task, were interrogated from several different perspectives, enabling a multidimensional understanding of the psychological and neural mechanisms underpinning memory for emotion-laden words in normal aging. Naturally, this may augment the risk for Type I error, especially when using a more modestly sized sample, which was taken into account by correcting for multiple comparisons in various ways.

Even though Study II did not yield valence and/or arousal interaction effects with age, it still demonstrated, together with the behavioral results in Studies III and IV, the pertinence of considering both valence and arousal as contributing factors to memory for emotion-laden stimuli. Study II showed that these affective dimensions were largely interrelated in terms of *qualitatively variable* measure-specific interaction effects. Based on these results, it could therefore not be argued that it would be futile to attempt to disentangle the effects of these dimensions on cognition. However, these results also suggest that it is not possible to achieve total separation of the effects of these dimensions. There is a general debate on the nature of the relationship between these affective dimensions. There is no consensus in the literature on how this relationship should be defined, just as there is no consensus on how to define emotions in general. Some researchers contend that these affective dimensions are orthogonally related, bipolar, and independent (Dolcos et al., 2017) based on the observation of an asymmetrical relationship between them in the affective space (Fairfield et al., 2017; Osgood et al., 1957). In Study I, the relationship resembled the typical curvilinear shape, but there was no valence-arousal correlation for nouns rated as positive. Others hold that valence and arousal are interrelated constructs (e.g., Hamann, 2003), even to the point that separating them could be considered as artificial. In a healthy individual, the effects of valence and arousal are integrated in the perception, evaluation, and experience of stimuli and events, which in turn means that the effects of valence and arousal may be difficult to disentangle also at the neurophysiological and neuroanatomical level (Dolcos et al., 2017; Russell, 2003). In fact, Russell (2003) pointed out that the conscious experience of core affect constitutes an integral blend of hedonic values (i.e., valence) and arousal. Also as stimulus characteristics they are quite often confounded (e.g., Keil & Freund, 2009; Waring & Kensinger, 2009), which is a potential source for systematic error in experiments using these stimuli. The distinct relationship between valence and arousal for negatively and positively valenced words in Study I could be said to be such a source. Importantly for the body of work in this thesis, Study I indicated that the relationship between these affective dimensions (e.g., Fairfield et al., 2017; Keil & Freund, 2009) and even between the extreme poles of valence would seem to change with age (Magai, Consedine, Krivoshekova, Kudadjie-Gyamfi, & McPherson, 2006), affecting emotional experience. However, this was not reflected in the results of Study II, as age did not interact with other relevant factors.

The predictions were largely tentative in Studies III and IV, as very little was known about the neuroanatomical (or electrophysiological) correlates of memory for emotion-laden words in healthy middle-aged and older adults at the time of data collection. Therefore, whole brain approaches were favored to accommodate for making few or no *a priori* assumptions. The studies produced several novel findings. Their results were more in line with the CCM/SST account than the deficit-based DIT or ABM accounts, but it should be noted that these theories were not directly tested in these two studies, as it was not possible to include a young adult group for practical reasons. Naturally, the lack of a young adult group will mean that one should exert caution in interpreting the present results. The behavioral study II, which included a young adult group, offered very little evidence to support either type of theoretical framework, although it should be emphasized that the age-related positivity effect in memory (Reed et al., 2014) and the associated neural activation and connectivity patterns tend to surface specifically in healthy adults older than 70 years (Ford & Kensinger, 2014, 2017). The older adult group in the present study had a mean age of 62.54 years. The novel results in terms of unexpected localizations and directions of the correlations in Studies III and IV indicate that the structure-function relationships for emotional memory in cognitively intact middle-aged and older adults hold unique qualities. Thus, these studies suggest that the neuroanatomical correlates of emotional memory may indeed be distinct for healthy aging and various forms of neuropathology (cf. Kumfor et al., 2013). Therefore, these correlates should be investigated separately in these groups, rather than using mixed groups of patients with neurodegenerative diseases and healthy controls to boost variability in measures to enhance statistical power. After all, results of studies on GM volumetric correlates of behavior tend to depend on the age of the participants and the presence of brain pathology (Maillet & Rajah, 2013), assumedly reflecting variable microstructural mechanisms underlying regional GM volume as measured by VBM in young adults, normally aged adults, and people with neuropathological conditions (Kanai & Rees, 2011; Maillet & Rajah, 2013). Regarding WM microstructural correlates, the age-related changes may also be said to reflect the presence of brain pathology, even though WM changes in normal aging tend to be less severe than in disconnection syndromes, which are thought to yield variable behavioral effects (Charlton et al., 2013). Moreover, divergent functional brain activation and connectivity patterns during emotional pattern separation were demonstrated for older adults differing in memory proficiency (Leal et al., 2017), suggesting that it would be fruitful to consider such individual variability in future studies on age-specific neuroanatomical substrates of emotional memory as well. Furthermore, on a general level, the counterintuitive directionality of some of the results in Studies III and IV indicates that much remains to be resolved as to the relationship between size or integrity of brain structure, functional efficiency, and behavioral outcomes. The general assumption is that there is a positive correlation between the size or integrity of brain structures and their functional efficiency (in terms of both functional activation and cognitive/behavioral efficiency). However, the relationship between structural size and functional efficiency has been shown to differ according to memory process (encoding, retrieval) and brain region, even within the PFC, in older adults (Kalpouzos, Persson, & Nyberg, 2012). Stern et al. (2005) argued that the processing efficiency of cortical structures may be related to their functional efficiency *apart from* their size, which would imply that when less tissue is associated with stronger activation to produce higher levels of a given behavior, a compensatory mechanism may be involved. Elucidation of these issues would demand addressing some of the limitations of Studies III and IV, such as including young adults and patients as well as conducting a multi-method study to explore both structure-function relationships and the activation of the implicated brain areas during task performance. It should be emphasized that the interpretation of the present results is based on correlative evidence that comes with important limitations. As causal inferences cannot be made, we do not know whether the brain areas and connecting pathways identified in this thesis indeed constitute the necessary and sufficient neural substrates of immediate free recall and recognition of a certain type of words. Taking the present lack of amygdalar correlations as an example, one cannot infer from this that the amygdalae would not be related to memory for emotion-laden words. Both lesion studies (Adolphs et al., 1997; Phelps et al., 1997) and functional brain imaging studies (e.g., Canli et al., 1999; Fischer et al., 2010) suggest otherwise.

It is possible that the results in Studies II-IV partly reflect the choice of words as experimental material. Studies have shown that processing of emotional content in words elicits different behavioral and neural responses than processing of emotional content in other types of stimulus material, such as pictures (e.g., Hinojosa et al., 2009; Mather, 2016), also in an age-specific manner (for a review, see Mather, 2016). This may indicate the ability of pictorial stimuli to induce stronger physiological arousal than words (Hinojosa et al., 2009). However, words do elicit effects of emotion on memory, which was demonstrated in Studies II-IV. Furthermore, in Study II, the effects of emotion on memory for words showed distinct valence-arousal patterns for different measures, albeit age-invariant ones. Nevertheless, it is likely that the results in these studies cannot be generalized to other stimulus materials.

5.1. Limitations

It could be considered a limitation that the effects of valence and arousal on memory were not investigated in a manner akin to Study II in the neuroanatomical studies III and IV. For these studies, the word lists were created by categorizing the words by their valence, but the positive and negative words could not be matched for their level of arousal. Consequently, the effects of valence and arousal on memory performance were intertwined, which naturally affected the explanations of our structure-function correlations. In other words, it is impossible to draw firm conclusions as to whether the neuroanatomical localizations of the correlations in these studies are related to valence, arousal, or some combination of the two dimensions. Furthermore, the limitation mentioned in Section 4.2 that memory performance may have been affected by experiment-related anxiety pertains to the results of Studies III and IV as well.

Using standardized valence and arousal evaluations to create word valence categories constitutes a limitation, as it has been shown that effects of emotional stimulus content on memory performance may be a function of whether objective or subjective ratings are used (Kensinger, Brierley, Medford, Growdon, & Corkin, 2002). Kensinger et al. (2002) reported an age-related interaction between perceived emotional content in words and word recall from memory, specifically when the subjects' own affective ratings were used to group the stimuli according to emotional content. When the ANEW ratings (by young adults) were used, there was no significant interaction between age and valence in memory performance. However, it should be pointed out that the raters for the normative database in the present thesis ranged in age between 16 and 77 years. Still, this fundamental issue also concerns the achievable level of experimental control in experiments using emotion-laden stimuli, pertaining to what could be construed as *objective* ratings of emotional content in stimuli. A high level of objectivity would require a low degree of variability (= little individual, subjective variation) in the ratings. This was not achieved for most of the words in the database in Study I. Furthermore, the general consensus among scholars would hold that the appraisal of emotional content in a stimulus is a result of the net effect of several interrelated variables, including but not limited to macro- and micro-cultural aspects, situational aspects in time and space, and individual characteristics molded during the course of the individual's personal history (Scarantino, 2016). Interestingly, in the database in Study I, intuitively neutral words such as 'pine tree' (*mänty* in Finnish) were rated as positive on average, reflecting this notion. Also, age and gender effects on ratings of emotional content should therefore be understood as reflecting cohort effects. In fact, Study I demonstrated that interactions between various factors rather than their main effects explained valence and arousal ratings of words. Using the individual's own stimulus evaluations should help in gaining a more accurate understanding of what s/he remembers and how. Consequently, using the subjective ratings for the analyses could have produced different, and perhaps more valid and replicable results.

Another limitation in Studies II-IV consists in the use of emotionally homogeneous word lists and a higher frequency of emotion-laden (67%) than emotionally neutral stimuli. This may result in directing attention to the emotional content of the words, thus preventing self-directed processing, which is required for the positivity effect to emerge (cf. Adelman & Estes, 2013; Reed et al., 2014). Effects of valence and arousal also seem to be affected by this. When using an experimental paradigm without emotion focus, only effects of valence on recognition memory emerged, leading the authors to propose that recognition memory accuracy is unrelated to arousal, if emotion is not specifically attended to (Adelman & Estes, 2013). Also, no buffer words at the beginning or end of the word lists were used to control for primacy or recency effects in the present thesis.

The cross-sectional design presents with some limitations to all the studies in the present thesis. Because cross-sectional data constitute a collection of independent observations of a phenomenon at a point in time (Unger, van Belle, & Heyman, 1999), only differences in the characteristics between the age groups (Birren & Cunningham, 1985), not change, can be studied with this setup. Therefore, the body of work in this thesis is to be characterized as descriptive, because it cannot be discerned what is related to aging *per se* and what is related to other aspects of individual variation. In Studies III and IV, this problem was amplified in that no young adults were included, and the age range (50-79 years) was truncated. Therefore, this precludes an estimation of whether the results reflect experience-dependent changes or degenerative processes coinciding with normal cognitive aging. As an example, better performance on an attentionally demanding oddball task correlated with higher FA in distinct WM tracts for young and older adults (Madden et al., 2004). This could suggest that different anatomical pathways may be used to perform the same cognitive tasks because of aging-related degenerative effects on the WM tracts employed in younger age (Scholz et al., 2014). Descriptive evidence is typical for cross-sectional aging research. Age by its nature cannot be said to *cause* a certain facet of behavior, it can only be said to *indicate* that behavior (Settersten & Godlewski, 2016). For example, the fact that older adults tend to report higher levels of emotional well-being (Charles & Carstensen, 2010) does not mean that older age *causes* this phenomenon. Instead, it merely constitutes a description of the state of affairs in that age segment, representing a particular cohort. Only longitudinal research using samples representative of the entire adult lifespan can be used to delineate effects of aging processes (Birren & Cunningham, 1985).

A related issue is that heterogeneity in terms of individual variation is rather the norm than the exception, when it comes to emotional processing (e.g., Mather & Knight, 2005), neuropsychological attributes (e.g., Small, 2001), and structural brain correlates (e.g., Raz & Daugherty, 2018) of older age. This may be due to the inadvertent inclusion of older adults suffering from preclinical neurodegenerative diseases in the sample (Sliwinski, Lipton, Buschke, & Stewart, 1996), but it is also known that healthy aging can take several different trajectories (Nyberg et al., 2012). Furthermore, attributing these findings solely to aging processes can be considered rather simplistic and reductionist. Several studies have endorsed a multifaceted and multidimensional view of the mechanisms that drive cognition-emotion interaction in general, as well its relationships with age (e.g., Labouvie-Vief, 2003; Mather & Knight, 2005; Reed et al., 2014).

Another related issue pertains to the differentiation of life phases based on chronological age, especially regarding middle and older adulthood. It can be considered as rather arbitrary. According to Settersten and Godlewski (2016), Neugarten coined the terms that are currently used to separate relatively well-functioning older adults from those who are not, highlighting the heterogeneity inherent in older age segments. Later, the boundaries have become fixed, and scientists try to characterize aging processes within these somewhat arbitrarily defined age segments (Settersten & Godlewski, 2016). Some researchers have now attempted to redefine these groups in terms of level of functioning instead of chronological age.

Studies II-IV share some other limitations, pertaining to potential selection biases that may affect the generalizability of the results. The main study was conducted using convenience samples of self-selected young, older middle-aged and older adults. However, the sample as whole was quite representative of its age segment in terms of gender and educational attainment (Statistics Finland, 2016). It is likely that the findings in Study III and IV can in part be attributed to the sample size of the older adult group. Even though the present sample size of 46 individuals was larger than in previous related research, it might not have been large enough to produce the variability needed in volumetric, microstructural WM, and memory measures for detecting significant associations. For example, it has not been established whether healthy neurocognitive aging is accompanied by decline in amygdalar volume, because the findings have been inconsistent (Fjell et al., 2009; Fjell et al., 2013; Grieve et al., 2005; Jernigan et al., 2001; Mather, 2016). Still, it is likely that the present study lacked sufficient statistical power, because the sample size can be considered modest given the number of predictors/covariates in these analyses (cf. Tabachnick & Fidell, 2007, for some rules of thumb). This is a common issue within this field of research, which pertains to the "replicability crisis” within psychological research. Also, considering that many of the findings were novel, they may be found to be unique to this particular study, either despite or because of the fact that the sample was particularly rigorously examined for cognitive, psychiatric, and neurological health. As for Studies III and IV, the time interval between the EEG experiment (behavioral tasks) and the MRI scan was quite long, 13.4 weeks on average.

5.2. Future directions

In conclusion, the present thesis serves to show that much remains to be elucidated about the psychological and neural mechanisms that drive the cognition-emotion interactions in normal aging. In their recent review, Kensinger and Gutchess (2017) laid out how various theories of cognitive aging could be harnessed to explain age-related changes in socioaffective domains of psychological functioning, but they also identified important points of departure. They showed that the interplay between the three psychological constructs cognition, emotion, and motivation, and the changing face of this interplay over the adult lifespan is indeed multifaceted, with intersecting, bidirectional, and divergent trajectories for specific cognitive and socioaffective abilities. Furthermore, it is quite likely that there is heterogeneity in individual trajectories also in socioaffective aging. Future studies face the challenge of clarifying the multiple and various facets of “the paradox of aging”.

To ascertain which factors interacted to produce the present results would require further studies using another, ideally larger sample extending over the adult lifespan to permit age comparisons and assessments of the effects of other individual differences, using word stimuli free of the current confound of distinct valence-arousal relationships at both ends of valence polarity, and using subjective ratings to group the stimuli. Among the individual differences of particular interest would be cognitive control ability, the effect of which should be examined with a comprehensive test battery that was not in use here. Also, to be able to test predictions of the various theories on age-related changes in cognition-emotion interaction, a longitudinal setup would be warranted. To my knowledge, no longitudinal studies within this field of research have been published so far. Furthermore, the intricate relationship between neural structure and function in cognition-emotion interaction in aging would be best examined in an event-related experimental paradigm, which would enable assessment of the impact of structural correlates on the functional efficiency of the implicated brain areas. In light of the complexity of the research question, integrative approaches to investigating into the intricate cognition-emotion relationships in aging and the mechanisms that drive them are called for. Promising novel avenues have surfaced in recent years, such as characterizing a possible genetic profile for the age-related positivity effect (for a review, see Mammarella, Di Domenico, & Fairfield, 2016) and examining the role of the noradrenergic system in generating this effect (for a review, see Mammarella, Di Domenico, Palumbo, & Fairfield, 2016). The development of integrative frameworks for understanding these phenomena is facilitated by the contemporary advances in gathering and analyzing multilevel and multidimensional data to create models that permit assessing distinct contributions of various processes as well as their interrelationships. The present thesis set out to move towards such an approach. Furthermore, using words as experimental stimuli cannot be said to capture the phenomenon of memory for emotion-laden stimuli and events, in that their ecological validity is limited. To be able to achieve that end and to still be able to strive for experimental control, more innovative stimulus materials than those traditionally employed in memory research should be used, such as virtual reality systems.

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